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EXHAUST EMISSIONS FROM UNCONTROLLED VEHICLES AND RELATED EQUIPMENT USING INTERNAL COMBUSTION ENGINES. PART 4. SMALL AIR-COOLED SPARK IGNITION UTILITY ENGINES

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Southwest Research Institute

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Exhaust emissions from five gasoline-fueled, air-cooled utility engines were measured using two types of steady-state procedures, and some measurements were taken during transient operation. The engines tested were a 3.5 hp engine with a vertical crankshaft, a 4 hp model, an 18 hp model, a 2 hp model, and a 12.5 hp model. The 18 hp engine was a 2-cylinder model, and the remaining engines ~~were~~ single-cylinder units. The 2 hp engine was a 2-stroke, and the remaining engines were 4-strokes. Engines of this type are often referred to as "small tility engines" or just "small engines". The two procedures used for small engine tests were a 9-mode procedure which was being recommended by SAE at the time the tests were run (early 1971), and a modified version of the "EMA-California" 13-mode procedure. The exhaust products measured included ~~total hydrocarbons by FIA~~ hydrocarbons, CO, CO_2, ~~and~~ NO ~~by NDIR;~~ O_2 ~~by electrochemical analysis~~; light hydrocarbons ~~by gas chromatograph;~~ total aliphatic aldehydes ~~(RCHO) and~~ formaldehyde (HCHO) by the MBTH and chromotropic acid methods, respectively; particulate by an experimental dilution-type sampling device; and exhaust smoke (2 hp 2-stroke engine only) using a PHS full-flow smokemeter. The engines were operated on small electric dynamometers, and the emissions results are used in conjunction with statistics on utility engine population and usage to estimate national emissions impact.

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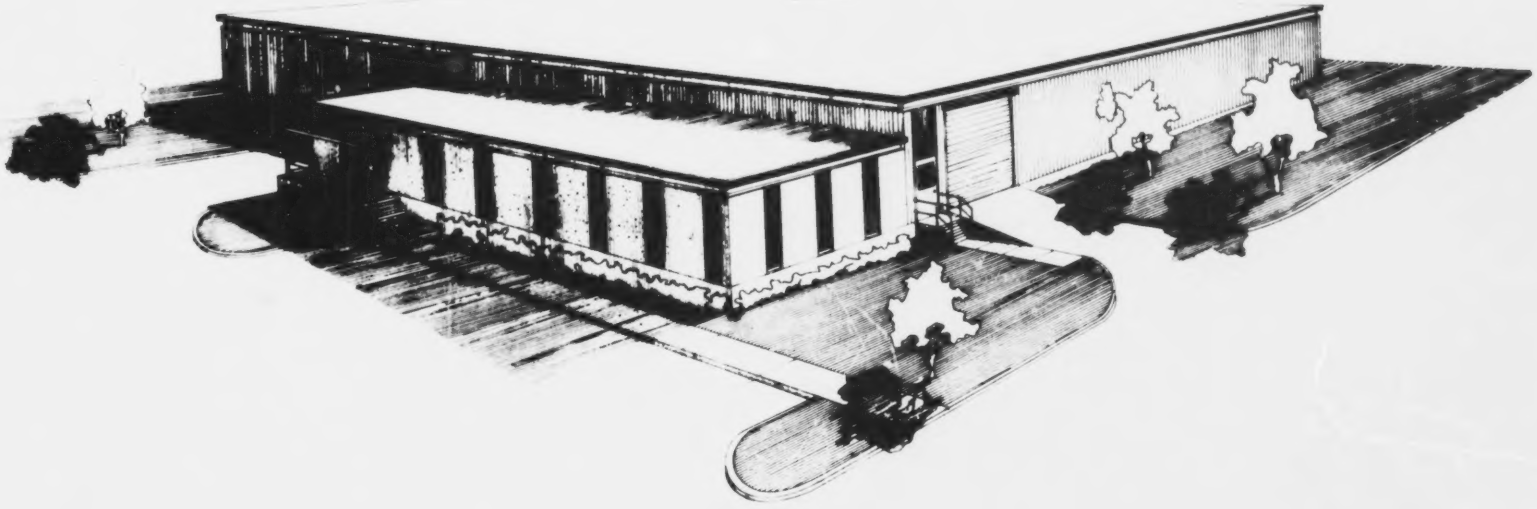

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EXHAUST EMISSIONS FROM UNCONTROLLED VEHICLES AND RELATED EQUIPMENT USING INTERNAL COMBUSTION ENGINES

by
Charles T. Hare
Karl J. Springer

FINAL REPORT
Part 4
SMALL AIR-COOLED SPARK IGNITION UTILITY ENGINES

Contract No. EHS 70-108

Prepared for
Emission Characterization and Control Development Branch
Office of Mobile Source Air Pollution Control
and
National Air Data Branch
Office of Air Quality Planning and Standards
Office of Air and Water Programs
Environmental Protection Agency

May 1973

Approved:

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Technical Vice President
Department of Automotive Research

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ABSTRACT

This report is Part 4 of the Final Report on Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines, Contract EHS 70-108. Exhaust emissions from five gasoline-fueled, air-cooled utility engines were measured using two types of steady-state procedures, and some measurements were taken during transient operation. The engines tested were a 3.5 hp Briggs & Stratton model 92908 (this engine was the only one with a vertical crankshaft), a 4 hp Briggs & Stratton model 100202, an 18 hp Kohler model K482, a 2 hp Tecumseh model AH520 type 1448, and a 12.5 hp Wisconsin model S-12D. The Kohler engine was a 2-cylinder model, and the remaining engines were single-cylinder units. The Tecumseh engine was a 2-stroke, and the remaining engines were 4-strokes. Engines of this type are often referred to as "small utility engines" or just "small engines".

The two procedures used for small engine tests were a 9-mode procedure which was being recommended by SAE at the time the tests were run (early 1971), and a modified version of the "EMA-California" 13-mode procedure. The SAE Small Engine Subcommittee has since revised its recommended procedure significantly, but the newer ideas had not been advanced when the subject tests were run.

The exhaust products measured during the emissions tests included total hydrocarbons by FIA; hydrocarbons, CO, CO_2, and NO by NDIR; O_2 by electrochemical analysis; light hydrocarbons by gas chromatograph; total aliphatic aldehydes (RCHO) and formaldehyde (HCHO) by the MBTH and chromotropic acid methods, respectively; particulate by an experimental dilution-type sampling device; and exhaust smoke (Tecumseh 2-stroke engine only) using a PHS full-flow smokemeter.

The engines were operated on small electric dynamometers, and the emissions results are used in conjunction with statistics on utility engine population and usage to estimate national emissions impact.

FOREWORD

The project for which this report constitutes part of the end product was initiated jointly on June 29, 1970 by the Division of Motor Vehicle Research and Development and the Division of Air Quality and Emission Data, both divisions of the agency known as NAPCA. Currently, these offices are the Emission Characterization and Control Development Branch of MSACP and the National Air Data Branch of OAQPS, respectively, Office of Air and Water Programs, Environmental Protection Agency. The contract number is EHS 70-108, and the project is identified within Southwest Research Institute as 11-2869-001.

This report (Part 4) covers the small utility engine portion of the characterization work only, and the other items in the characterization work have been or will be covered by six other parts of the final report. In the order in which the final reports have been or will be submitted, the seven parts of the characterization work include; Locomotives and Marine Counterparts; Outboard Motors; Motorcycles; Small Utility Engines; Farm, Construction and Industrial Engines; Gas Turbine "peaking" Powerplants; and Snowmobiles. Other efforts which have been conducted as separate phases of Contract EHS 70-108 include: measurement of gaseous emissions from a number of aircraft turbine engines; measurement of crankcase drainage from a number of outboard motors; and investigation of emissions control technology for locomotive diesel engines; and those phases either have been or will be reported separately.

Cognizant technical personnel for the Environmental Protection Agency are currently Messrs. William Rogers Oliver, and David S. Kircher, and past Project Officers include Messrs. J. L. Raney, A. J. Hoffman, B. D. McNutt, and G. J. Kennedy. Project Manager for Southwest Research Institute has been Mr. Karl J. Springer, and Mr. Charles T. Hare has carried the technical responsibility.

The offices of the sponsoring agency (EPA) are located at 2565 Plymouth Road, Ann Arbor, Michigan 48105 and at Research Triangle Park, North Carolina 27711; and the contractor (SwRI) is located at 8500 Culebra Road, San Antonio, Texas 78284.

Several groups and individuals have contributed to the success of the small utility engine part of this project. Appreciation is first expressed to Briggs & Stratton Corporation, Kohler Co., and Teledyne Wisconsin Motor for providing engines on a loan basis for test purposes. The cooperation of Tecumseh Products Co. is also appreciated, although the Tecumseh engine was purchased by the contractor (not using contract funds) rather than being obtained on loan. Individuals within these companies who provided technical assistance included Messrs. George Houston of Briggs & Stratton, Larry Bernauer of Kohler, K. S. Sanvordenker of

Tecumseh, and John Gresch of Teledyne-Wisconsin. Additional assistance was provided by Mr. Barton H. Eccleston of the Bureau of Mines and the SAE Small Engine Subcommittee as a whole.

The SwRI personnel involved in the small engine tests included Harry E. Dietzmann, research chemist; Russel T. Mack, lead technician; and Joyce McBryde and Joyce Winfield, laboratory assistants. These people all made major contributions which are sincerely appreciated.

TABLE OF CONTENTS

		Page
ABSTRACT		ii
FOREWORD		iii
LIST OF ILLUSTRATIONS		vii
LIST OF TABLES		ix
I.	INTRODUCTION	1
II.	OBJECTIVES	2
III.	INSTRUMENTATION, TEST PROCEDURES, AND CALCULATIONS	3
	A. Analytical Instrumentation and Techniques	3
	B. Description of the "SAE 9-Mode" Emissions Test Procedure	10
	C. Description of the "Modified EMA 13-Mode" Emissions Test Procedure	12
	D. Estimation of Unmeasured Emissions	13
	E. Measurement of Emissions During Transients	15
IV.	EMISSIONS TEST RESULTS	17
	A. Gaseous Emissions	17
	B. Smoke Emissions (2-stroke engine only) and Particulate Emissions	33
	C. Emissions During Transients	37
V.	ESTIMATION OF EMISSION FACTORS AND NATIONAL IMPACT	40
	A. Development of Emission Factors	40
	B. Estimation of National Impact	45
VI.	SUMMARY	53
LIST OF REFERENCES		55

TABLE OF CONTENTS (Cont'd)

APPENDIXES

A. Emissions Data From 13-Mode Tests
B. Emissions Data From 9-Mode Tests and From 30-Mode Test on B & S 92908 Engine
C. Graphical Representation of Emissions During Transient Conditions

LIST OF ILLUSTRATIONS

Figure		Page
1	Main Gaseous Emissions Analysis System	4
2	FIA Control Unit (foreground) and Oven/Detector Unit (background)	4
3	NDIR Hydrocarbon and (High-range) CO Analyzers	4
4	Bubblers for Aldehyde Sampling and Gas Chromatographs for Light Hydrocarbon Analysis	4
5	Air Flow Measurement System Used for Small Engine Tests	6
6	Details of Exhaust System Typical of Those Used for Small Engine Tests	6
7	Experimental Dilution-Type Particulate Sampler	6
8	PHS Full-Flow Light Extinction Smokemeter	6
9	Briggs & Stratton 100202 Engine on Test Stand, First View	8
10	Briggs & Stratton 100202 Engine on Test Stand, Second View	8
11	Kohler K482 Engine on Test Stand, First View	8
12	Kohler K482 Engine on Test Stand, Second View	8
13	Wisconsin S-12D Engine on Test Stand, First View	9
14	Wisconsin S-12D Engine on Test Stand, Second View	9
15	Tecumseh AH520 Type 1448 Engine on Test Stand, First View	9
16	Tecumseh AH520 Type 1448 Engine on Test Stand, Second View	9

LIST OF ILLUSTRATIONS (Cont'd)

Figure		Page
17	Briggs & Stratton 92908 Engine Driving AC Generator Used as Dynamometer	11
18	Wattmeter (center) Used to Measure Power Output of Briggs & Stratton 92908 Engine	11
19	Variable Transformer Used to Control Load on Briggs & Stratton 92908 Engine	11
20	Resistive Load Bank Used to Dissipate Power Generated by Briggs & Stratton 92908 Engine	11
21	Hydrocarbon Emissions from Small Engines as Functions of Load and Speed	25
22	CO Emissions from Small Engines as Functions of Load and Speed	26
23	NO_x Emissions from Small Engines as Functions of Load and Speed	27
24	Aldehyde Emissions from Small Engines as Functions of Load and Speed	28
25	2% Opacity Smoke from Tecumseh 2-stroke Engine	36
26	3% Opacity Smoke from Tecumseh 2-stroke Engine	36
27	5% Opacity Smoke from Tecumseh 2-stroke Engine	36
28	6% Opacity Smoke from Tecumseh 2-stroke Engine	36

LIST OF TABLES

Table		Page
1	Test Conditions for SAE 9-Mode (1971) Procedure	10
2	Test Conditions for "EMA" 13-Mode Procedure	13
3	Mass Emissions from Small Engines Operated on the 9-Mode Procedure	18
4	Hydrocarbon Emissions from Small Engines by Load and Speed in Mass Rates (g/hr) and Brake Specific Rates (g/hphr)	19
5	Carbon Monoxide Emissions from Small Engines by Load and Speed in Mass Rates (g/hr) and Brake Specific Rates (g/hphr)	20
6	Oxides of Nitrogen (NO_x) Emissions from Small Engines by Load and Speed in Mass Rates (g/hr) and Brake Specific Rates (g/hphr)	21
7	Aliphatic Aldehyde (RCHO) Emissions from Small Engines by Load and Speed in Mass Rates (g/hr) and Brake Specific Rates (g/hphr)	22
8	Summary of 13-Mode Composite Emissions Results for Small Engines	24
9	Average Mode Brake Specific Emissions from Small Engines	29
10	Average Light Hydrocarbon Emissions from a Briggs & Stratton 92908 Engine	30
11	Average Light Hydrocarbon Emissions from a Briggs & Stratton 100202 Engine	31
12	Average Light Hydrocarbon Emissions from a Kohler K482 Engine	32
13	Average Light Hydrocarbon Emissions from a Tecumseh AH520 Engine	33
14	Average Light Hydrocarbon Emissions from a Wisconsin S-12D Engine	34

LIST OF TABLES (Cont'd)

Table		Page
15	Summary of Light Hydrocarbon Analysis for Small Engines	35
16	Average Smoke Opacity from a Tecumseh AH520 2-stroke Engine, 1-inch Diameter Pipe	37
17	Particulate Emissions from Small Utility Engines	38
18	Small Engine Evaporative Emission Estimates	44
19	Emission Factors for Small Utility Engines	46
20	Previous Estimates of Nationwide Small Engine Populations (1968)	46
21	Outdoor Equipment Sales and Population Estimates	47
22	Breakdown of 1966-1970 Small Engine Production by Application	47
23	Estimates of Current Small Engine Populations (12/31/72)	48
24	National Emissions Impact Estimates for Small Engines	50
25	Comparison of Small Engine National Impact Estimates with EPA Nationwide Air Pollutant Inventory Data	51
26	Summary of Seasonal, Regional, and Urban-Rural Variations in Small Engine Emissions	51

I. INTRODUCTION

The program of research on which this report is based was initiated by the Environmental Protection Agency to (1) characterize emissions from a broad range of internal combustion engines in order to accurately set priorities for future control, as required, and (2) assist in developing more inclusive national and regional air pollution inventories. This document, which is Part 4 of what is planned to be a seven-part final report, concerns emissions from small utility engines and the national impact of these emissions.

Some emissions data on small engines were becoming available at about the time the subject work was being performed(1, 2), which was approximately February through May 1971. These additional data helped, but were of limited usefulness due to the operating conditions at which the engines were run. The procedures used for the subject work were chosen with the intent of gathering the most useful results, but little consideration has been given to the potential usefulness of these procedures for anything except research purposes. All the subject tests were performed in the SwRI Automotive Research and Emissions Research Laboratories by members of the Emissions Research Laboratory staff.

The impact portion of this report was first presented in Quarterly Progress Report No. 6(3) on the subject contract (1/15/72).* Detail refinements and updated statistics have been incorporated into this Final Report.

*This report was published in the July 1972 issue of Automotive Engineering, the monthly journal of the Society of Automotive Engineers.

Superscript numbers in parentheses refer to the List of References at the end of this report.

II. OBJECTIVES

The objectives of the small utility engine part of this project were to obtain exhaust emissions data on a variety of engines, and to use these data along with available information on number of engines in service and annual usage to estimate emission factors and national impact. The emissions to be measured included total hydrocarbons by FIA; HC, CO, CO_2 and NO by NDIR; O_2 by electrochemical analysis; light hydrocarbons by gas chromatograph; aldehydes by wet chemistry; particulates by gravimetric analysis; and smoke (2-stroke engine only) by the PHS light extinction smokemeter. These exhaust consitutents are essentially the same as those measured during all tests on gasoline-fueled engines tested under this contract.

The objectives included implicitly the operation of test engines at a variety of loads and speeds to permit "mapping" exhaust characteristics. They also included use of either accepted or new calculation techniques to arrive at composite emissions which could be used to derive factors and national impact.

III. INSTRUMENTATION, TEST PROCEDURES, AND CALCULATIONS

Although two major types of test procedures were utilized during the small engine tests, the same instrumentation package and analysis techniques were used for both procedures. It seems logical, therefore, to consider the procedures separately from the standpoint of engine operation, but to describe the instrumentation package only once. Techniques used for estimation of emissions not measured (fuel evaporation and oxides of sulfur) are also outlined in a separate section.

A. Analytical Instrumentation and Techniques

Emissions measurements on the small spark-ignition utility engines were the first tests conducted under the subject contract, although reporting priorities on some of the other engine categories were higher. The delay caused by the priorities means that quite some time has elapsed since the small engine tests (about 20 months) and during this time a considerable evolution in instrumentation and techniques has taken place. Consequently, both hardware and methods employed for small engine tests and analysis may seem somewhat out of date compared with those used on other engine categories.

The emissions measured on a continuous basis during steady-state tests included total hydrocarbons by FIA; CO, CO_2, NO, and hydrocarbons by NDIR; and O_2 by electrochemical analysis. Attempts were made to measure total paraffins (and consequently total non-paraffins) using a subtractive column before the FIA, but the results were disappointing. It was likewise attempted to measure NO_2 using an electrochemical analyzer, but again no reliable results were achieved (the chemiluminescent instrument was not available at the time). Batch samples were taken over 3-minute periods for aldehyde analysis, using the MBTH method(4) for total aliphatic aldehydes (RCHO) and the chromotropic acid method(5) for formaldehyde (HCHO). Bag samples were also acquired for light hydrocarbon analysis (methane through butane - 7 compounds). The chromatograph employed for this latter analysis used a 10 ft. by 1/8 inch column packed with a mixture of phenyl isocyanate and Porasil C preceded by a 1 inch by 1/8 inch precolumn packed with 100-120 mesh Proapak N.

Some of the analytical instruments are shown in Figures 1-4, with Figure 1 showing instruments mounted in the main analysis cart (oxygen and electrochemical NO_x analyzers at top; NO, low-range CO, and CO_2 analyzers at center; 4-pen recorder bottom center). Figure 2 shows the FIA control unit and electrometer in the foreground, and the FIA oven/detector unit at left in the background. Cramped space prevented direct photographs of these instruments. Figure 3 shows the NDIR hydrocarbon analyzer and the high-range CO analyzer, mounted on a separate small cart. Figure 4 shows the gas chromatographs used for light hydrocarbon analysis, and the sample collection system for aldehydes (bubblers at left).

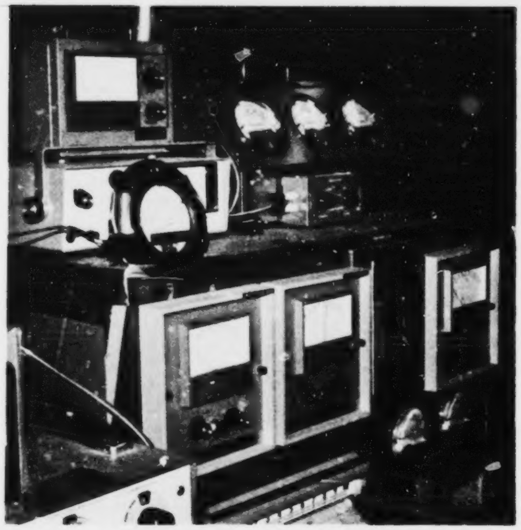

Figure 1. Main Gaseous Emissions Analysis System

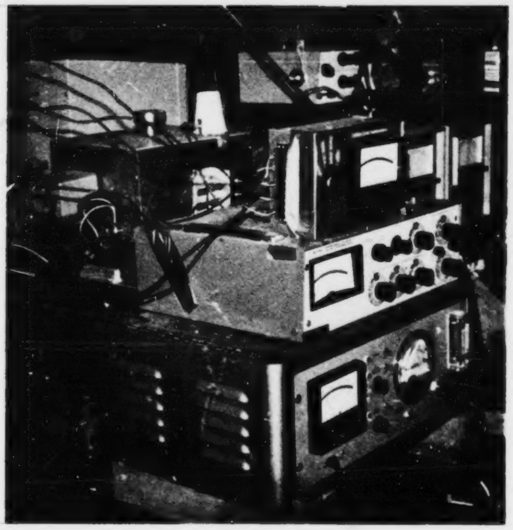

Figure 2. FIA Control Unit (foreground) and Oven/Detector Unit (background)

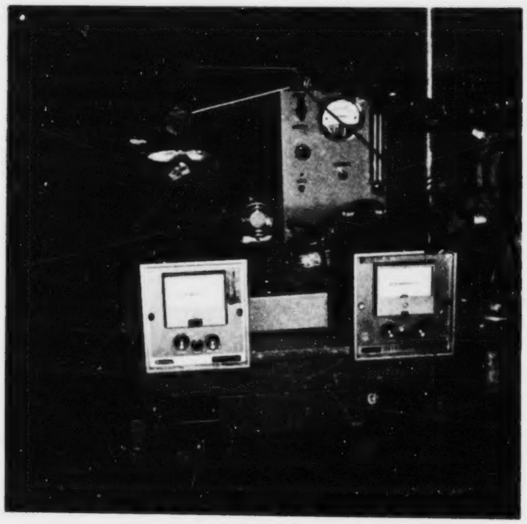

Figure 3. NDIR Hydrocarbon and (High-range) CO Analyzers

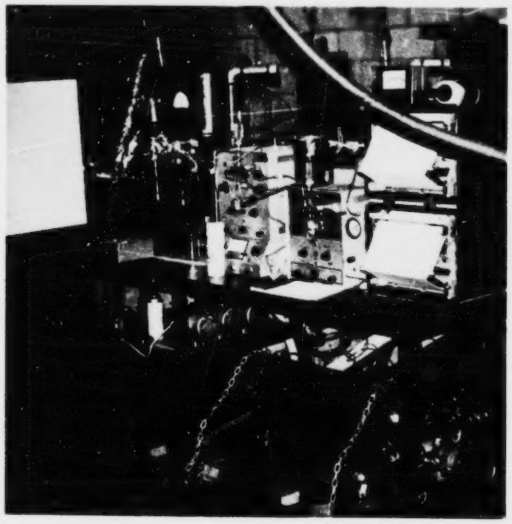

Figure 4. Bubblers for Aldehyde Sampling and Gas Chromatographs for Light Hydrocarbon Analysis

All the emission concentration data acquired on the small engines except FIA total hydrocarbons and aldehydes were on a "dry" basis, and were originally given on the dry basis in progress reports. For this report, however, all emission data are expressed on a wet basis except the data on concentrations during transients. Air and fuel rates were measured during the small engine tests where possible, but fuel system design of the two Briggs & Stratton engines made fuel measurement impractical. In these cases fuel rate was calculated from exhaust composition and air rate using the Spindt method(6). Air rates were measured using a laminar flow element such as that shown in Figure 5, and fuel rates were measured volumetrically using a graduated burette and timer.

It was considered desirable to test the engines with stock mufflers in place, but these mufflers had perforated outlets rather than tubular outlets, so adapters were made as shown in Figure 6 for the Kohler K482. The adapters were made of stainless steel, and served to connect the muffler outlet to the stainless steel "mixing chamber" suggested by SAE. The mixing chamber shown in Figure 6 was used on the two larger engines, and was fabricated from a stainless steel beaker with a considerable amount of reinforcement. A smaller chamber was used for the three smallest engines. The idea behind the mixing chambers was to make certain that the exhaust gases sampled were not stratified, that is, that they were part of a homogeneous mixture. It was found necessary in some cases to heat the mixing chambers to keep the wall temperatures at or above 160°F, considered to be the lowest acceptable temperature.

Figure 7 shows the experimental dilution-type particulate sampler used for small engine tests. This instrument was developed in order to meet contract objectives, and sample filtration occurred at about 85°F and 1 atmosphere. A sample of exhaust gas was withdrawn from a point downstream of the muffler (the mixing chamber was not used for particulate tests) at a rate as near isokinetic as possible, with sampling times of about 5 minutes. The sample was immediately mixed with a known flow of dilution air (prepurified dry compressed air) to cool it and prevent condensation of water, then filtered through a pre-weighed membrane filter having 0.45 micron mean flow pore size. The flow of dilute sample was then measured with a dry gas meter (continuously and totalized). Exhaust sample flow, which was set quite accurately by the two large flowmeters, was determined even more accurately by subtracting the dilution flow from the total flow. The filter was reweighed after use to determine the amount of particulate collected. It should be noted that although care was taken to withdraw sample from the exhaust pipe at a velocity equal to the bulk exhaust velocity, the sampling was not truly "isokinetic" due to exhaust pulsations and multidimensional flow in the pipe.

In total, about 120 particulate samples were acquired from the small engines, including several speeds and loads which were taken to be representative of normal operation. Unused filters were kept in a dessicated

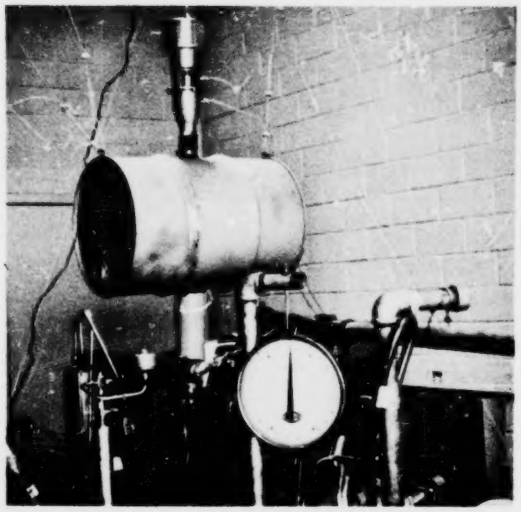

Figure 5. Air Flow Measurement System Used for Small Engine Tests

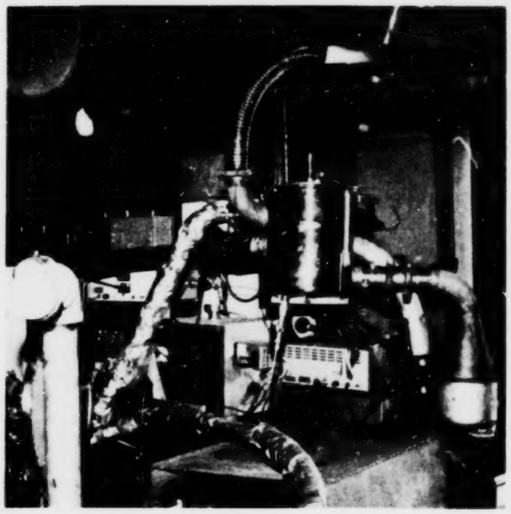

Figure 6. Details of Exhaust System Typical of Those Used for Small Engine Tests

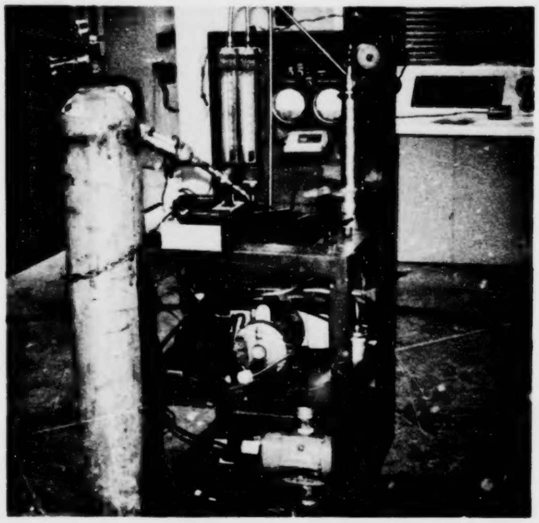

Figure 7. Experimental Dilution-Type Particulate Sampler

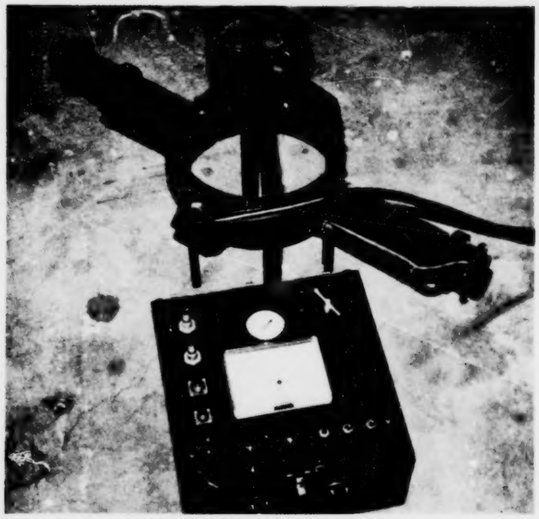

Figure 8. PHS Full-Flow Light Extinction Smokemeter

chamber, and were dried out again following use to establish a stable baseline. The balance used to weigh the filters (nominal weight 500 mg) had an accuracy of ±0.1 mg over the range of measurements taken, and the instrument "zero" was checked between each two independent weighings. The filters were weighed a minimum of four times both before and after use, and the last two weights had to be within 0.2 mg of each other. The last two weights were averaged to obtain the values used in computations. During the sampling period, temperatures and pressures were recorded throughout the system, permitting calculation of sample flowrate to 3 significant figures.

For the single 2-stroke engine tested, a Tecumseh 2 hp unit, exhaust smoke was measured using a PHS full-flow light extinction smokemeter such as the one shown in Figure 8. The conditions under which smoke opacity was measured included several loads and speeds, but the physical arrangement of the test cell dictated the use of a rather long exhaust pipe, which is considered undesirable for smoke tests. It should also be noted that the smoke opacity figures for the Tecumseh engine were based on a 1 inch diameter exhaust pipe, and that the PHS smokemeter was used as a research tool only and not because it is recommended for such use. The PHS meter probably gives reasonably accurate results on "white" smoke, but some research into the matter would be necessary before it could be recommended as a rigorous quantitative technique.

Due to different sampling system and operating schedules, particulate sampling could not be conducted while gaseous emissions were being measured. This comment on separate tests also applies to smoke measurements made on the Tecumseh 2-stroke engine.

The test engines and dynamometer equipment used are shown in detail beginning with Figure 9. Figures 9 and 10 show the 4 hp Briggs & Stratton model 100202 engine on the test stand, and Figures 11 and 12 show the 18 hp Kohler K482. The large metal enclosure covering the couplings and drive shaft was a safety shield, and it was used on three of the engines as permitted by sampling system configurations.

The 12.5 hp Wisconsin S-12D engine is shown in Figures 13 and 14, and the 2 hp Tecumseh AH520 engine is shown in Figures 15 and 16. Due to the location of the exhaust outlet on the Tecumseh (directly over the output shaft), a sharp right angle bend in the exhaust pipe was necessary to clear the flexible coupling as shown in Figure 16. Both the small coupling and the pipe configuration were considered undesirable from a technical standpoint, but neither appeared to affect the emissions results significantly.

The vertical-crankshaft Briggs & Stratton model 92908 engine required a different power absorption system, since it could not be operated

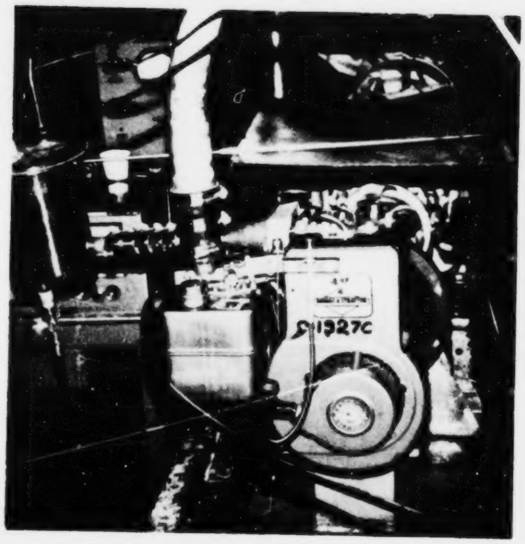

Figure 9. Briggs & Stratton 100202 Engine on Test Stand, First View

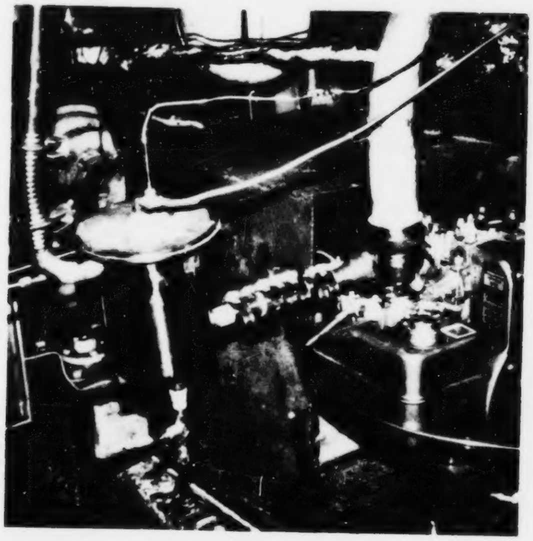

Figure 10. Briggs & Stratton 100202 Engine on Test Stand, Second View

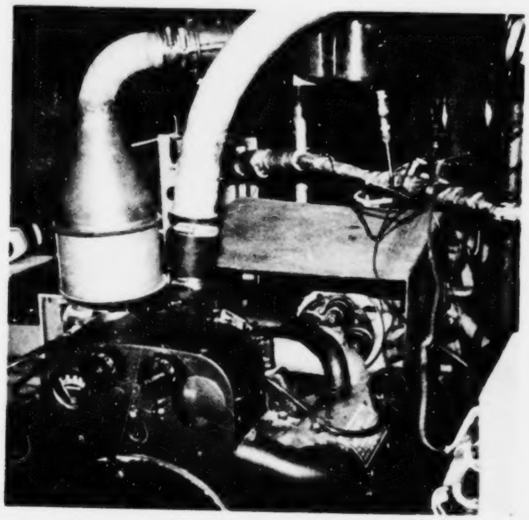

Figure 11. Kohler K482 Engine on Test Stand, First View

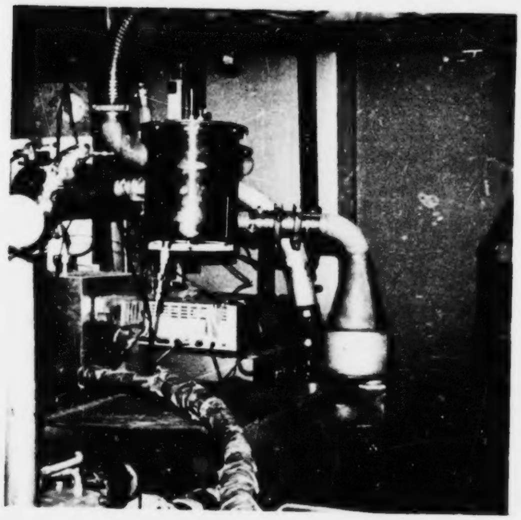

Figure 12. Kohler K482 Engine on Test Stand, Second View

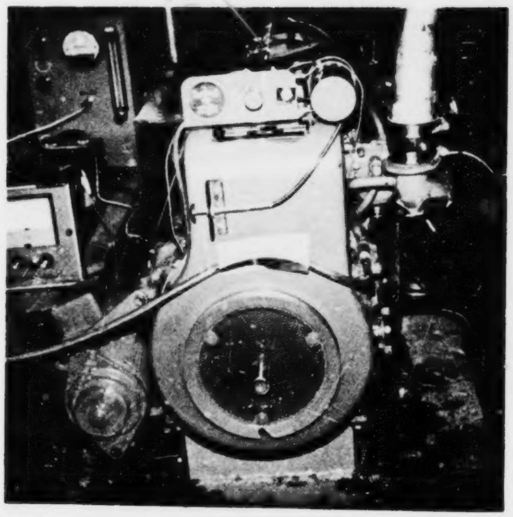

Figure 13. Wisconsin S-12D Engine on Test Stand, First View

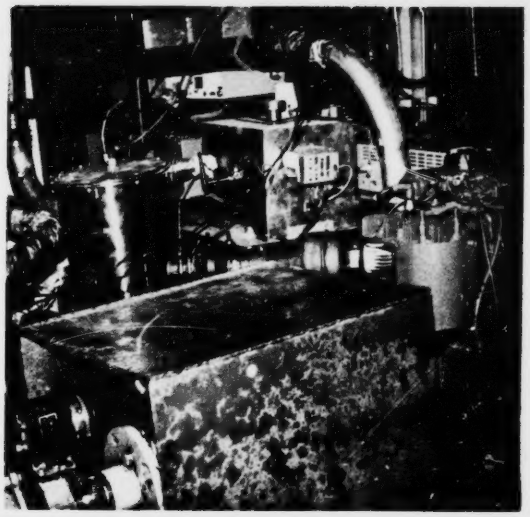

Figure 14. Wisconsin S-12D Engine on Test Stand, Second View

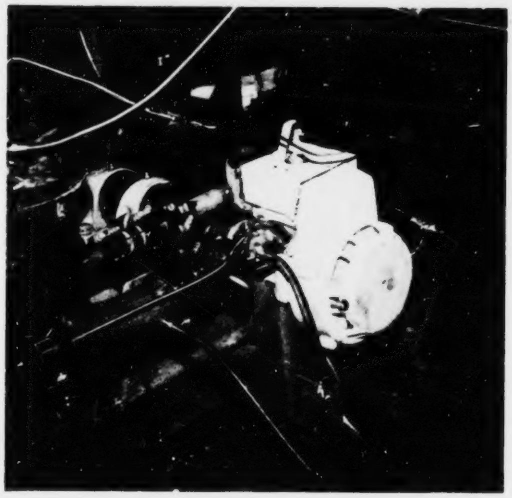

Figure 15. Tecumseh AH520 Type 1448 Engine on Test Stand, First View

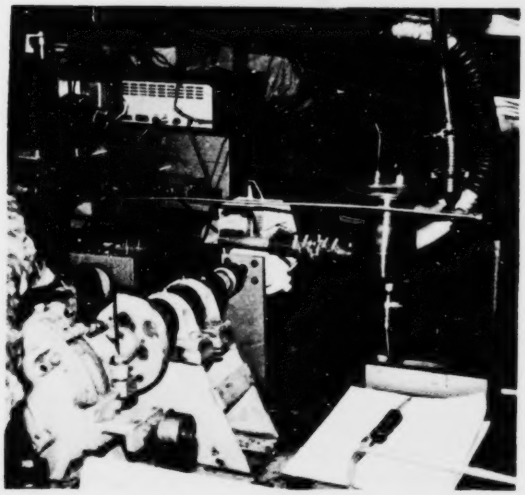

Figure 16. Tecumseh AH520 Type 1448 Engine on Test Stand, Second View

on a horizontal-shaft dynamometer. A special stand was constructed as shown in Figure 17, with a 3500 watt AC generator mounted underneath, its rotor supported by the engine crankshaft via a high-speed flexible coupling. The stroboscopic tachometer was used to set and measure engine speeds, but no analog rpm readout was installed. Figure 18 shows the wattmeter used to measure engine output (center of photograph). This instrument was placed in the line between the generator and the variable transformer shown in Figure 19. This transformer controlled the engine load, and power was dissipated in the resistive load bank shown in Figure 20.

B. Description of the "SAE 9-Mode" Emissions Test Procedure.

This test procedure represented a first attempt by the Small Engine Subcommittee of the SAE Engine Committee to arrive at a uniform way of gathering meaningful test data. Required emission measurements included hydrocarbons, CO, CO_2, and NO, with O_2 being required for 2-stroke engines only. The procedure called for a single operating speed (manufacturer's rated rpm), with a combination of loads and fuel/air mixture settings as described in Table 1. The procedure has some validity because many small engines operate at or near rated speed a majority of the time, but since other operating conditions are simply not represented, it is not very useful from the characterization standpoint. The three mixture settings were included in an attempt to represent the range of operating conditions which might be encountered in the field, but it was later decided that most engine operators could probably get reasonably close to the "lean best power" condition by simple

TABLE 1. TEST CONDITIONS FOR SAE 9-MODE (1971) PROCEDURE

Mode	Speed	*Fuel/Air Mixture	Load
1	Mfr. rated	Lean Best Power	Full
2	" "	" " "	Half
3	" "	" " "	None
4	" "	Fuel Rich	Full
5	" "	" "	Half
6	" "	" "	None
7	" "	Fuel Lean	Full
8	" "	" "	Half
9	" "	" "	None

*criteria explained in text

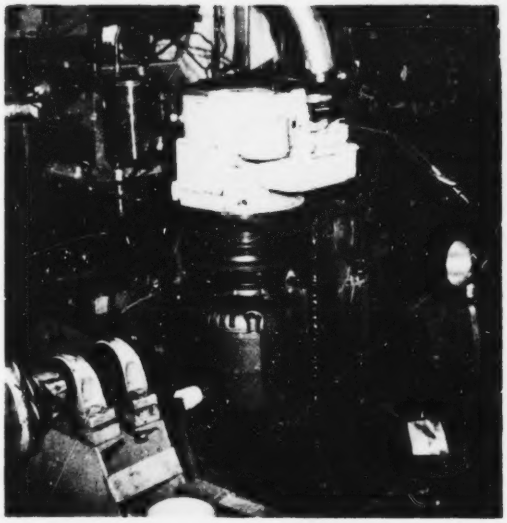

Figure 17. Briggs & Stratton 92908 Engine Driving AC Generator Used as Dynamometer

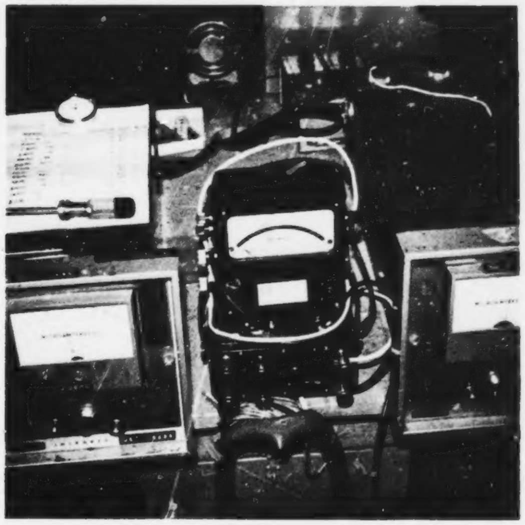

Figure 18. Wattmeter (center) Used to Measure Power Output of Briggs & Stratton 92908 Engine

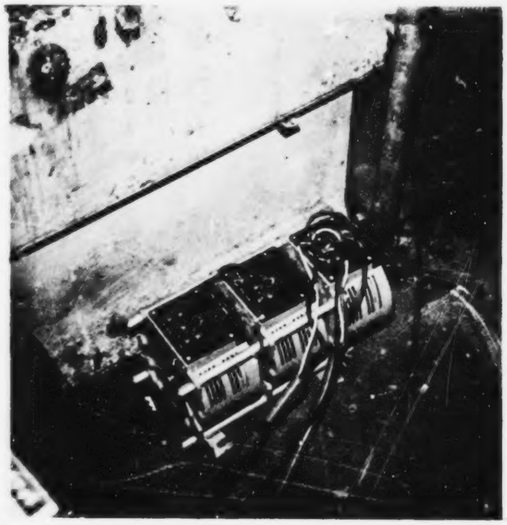

Figure 19. Variable Transformer Used to Control Load on Briggs & Stratton 92908 Engine

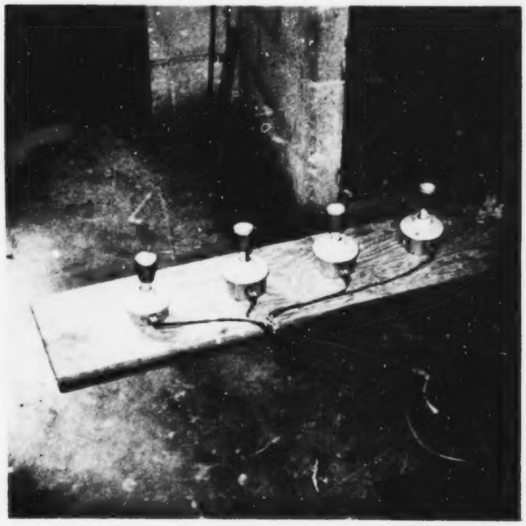

Figure 20. Resistive Load Bank Used to Dissipate Power Generated by Briggs & Stratton 92908 Engine

adjustment. Even if a considerable variation existed from engine to engine, it should be somewhat self-canceling due to errors on both the rich and the lean sides of "lean best power".

The "lean best power" carburetor setting was the leanest mixture the engine would tolerate at rated speed and full load without loss of power. The rich and lean conditions were arrived at by progressively changing the carburetor mixture setting in either the rich or the lean direction until a 1% drop in power was noted. Given the accuracy of dynamometer systems and the effects of vibration, these latter conditions were difficult to arrive at in a repeatable manner.

Each engine was tested on the SAE procedure at least twice, with one additional run on the Tecumseh AH520 engine (at lower-than-rated rpm) and one additional run on the Briggs & Stratton 92908. A variation on the SAE procedure was also run on the Briggs & Stratton 92908, having 30 modes and a total of four engine speeds as well as variation in mixture and load. No particular time interval was allotted to each mode of the procedure, but rather the stabilization of emissions and time required to obtain batch samples became the criteria. Normally, each mode required 10 minutes or more, with even longer times being the rule when the mixture was being changed. In order to set the mixture most accurately prior to modes 4 and 7, the lean best power condition was re-established before changing to the off-design condition. In some cases, the power at the re-established lean best power condition was quite different than that for mode 1 due to drifting with time; so power data for modes 4 and 7 may not be just less than for mode 1, as might be expected.

C. Description of the "Modified EMA 13-Mode" Emissions Test Procedure

Although other similarities existed, the only major points intentionally made common with the EMA-California procedure(7) for the subject tests were the speed-load schedule and the weighting factors given the modes. This 13-mode schedule is also the same as that to be used for gaseous emissions certification of new heavy- duty diesel engines beginning with the 1974 model year. The main reason for alluding to the "EMA" procedure at all is that it is familiar to many researchers in industry and government, which makes less explanation necessary.

A summary of the test conditions is given in Table 2, showing that this procedure essentially "maps" the emissions at two speeds as a function of load. The procedure was run as given three times on the Briggs & Stratton 92908, and twice on the other engines. In addition, another set of test conditions was chosen for each engine, except the Tecumseh. The new "rated" speed was set between the previously-run rated and intermediate speeds, and the new "intermediate" speed about 400 to 500 rpm below the previous intermediate speed. The idea of these changes was to acquire emissions data at two other speeds, to get a better picture of how emissions

TABLE 2. TEST CONDITIONS FOR "EMA" 13-MODE PROCEDURE

Mode	Speed	Load	Mode Weight
1	Low Idle	None	0.20/3=0.0667
2	*Intermediate	None	0.08
3	" "	25%	0.08
4	" "	50%	0.08
5	" "	75%	0.08
6	" "	Full	0.08
7	Low Idle	None	0.20/3=0.0667
8	Mfr's. Rated	Full	0.08
9	" "	75%	0.08
10	" "	50%	0.08
11	" "	25%	0.08
12	" "	None	0.08
13	Low Idle	None	0.20/3=0.0667
			$\sum = 1.00$

*peak torque speed or 60% of rated speed, whichever is higher

varied over the entire speed range. The procedure was then run once for each of the four engines.

For the 13-mode procedure as well as the 9-mode described earlier, the length of time spent in each mode was dictated by stability of emissions and batch sampling requirements, rather than the desire to run a mode in any particular time. The stabilization period for these small engines often did not consist of a gradual asymptotic approach to a constant value, but rather consisted of somewhat periodic variations around a central value. In this latter case, it was necessary to observe the chart readout for quite a long period of time to make certain that the correct central value was chosen. It is assumed that these small variations were due to inability of the engines to maintain a constant speed with precision, and also to the rather simple carburetion systems used (as compared to larger industrial engines).

As already noted, the weighting factors shown in Table 2 were used to calculate cycle composite emissions from the small engines. The rationale used to justify these factors is given in section V with the estimation of emission factors and national impact.

D. Estimation of Unmeasured Emissions

The subject contract was limited by time and financial constraints to measurement of those emissions which were considered most significant and for which reliable techniques were available. According to these criteria, it was decided to estimate emissions of sulfur oxides (SO_x) and evaporative hydrocarbons rather than attempt to measure them. Crankcase or "blowby" emissions were considered also, but all the 4-stroke engines tested had their crankcases vented to the carburetor, which eliminates crankcase emissions. Small 2-stroke engines such as the one tested use crankcase induction, so they produce no crankcase emissions. For calculation purposes, it will be assumed that the test engines are representative of standard practice, and thus that crankcase emissions from small engines are negligible.

Evaporative losses of hydrocarbons for which small engines are responsible include spillage during fueling operations (including mixing of oil and gasoline for 2-stroke machines), losses from the fuel tank and carburetor while running, and losses from the fuel tank and carburetor while the machine is stopped. Spillage losses are simply not within the scope of this contract, but other investigations (not specifically on small engines) are filling this need. Running losses from the fuel tank and carburetor are quite possibly significant, but no information is available from which they can be estimated intelligently. Evaporation while the machine is not in use is the only category of evaporative loss which can be estimated using available data, so all further discussion here will concern this type of loss alone.

Losses from the carburetor during the cool-down period of an automobile (called the "hot soak") are quite high because the engine is enclosed and has a large heat capacity, and because the carburetor sits on top of the engine. None of these three conditions holds for small engines, however, since their carburetors are generally side-draft and not mounted atop the engine, and since the engine is much smaller and less enclosed. Carburetor hot-soak losses are therefore probably small, and the rather small float chambers mean that diurnal breathing losses from the carburetor can probably be neglected, also. Elimination of the other evaporation processes then, has left diurnal loss from the fuel tank as the only significant evaporation loss which can be estimated from reasonable assumptions.

Diurnal breathing losses are primarily functions of fuel vapor pressure, vapor space in the tank, and the diurnal temperature swing. The standard low and high temperatures for evaporation loss measurements have been pretty well established at 60° F and 84° F, respectively, and several studies have been conducted to determine the effects of fuel Reid vapor pressure (Rvp), etc. Without going into too much detail, fairly accurate estimates can be made by assuming some typical Rvp for the fuel and dividing the numbers developed for cars at that Rvp by the applicable ratio of fuel tank volumes. For example, if 30 g/day tank HC loss were determined to be representative for a car with a 15 gallon tank, a comparable value for a small engine with a 1 gallon tank would be 30/(15/1) g/day or 2g/day if Rvp and the temperature extremes were held constant. Based on the results of several studies(8, 9) and the assumption that a summer fuel Rvp of 9.0 psi is typical(10), the factor to be used for small engine evaporative emissions is 2.0 g HC/(gallon tank volume day). This figure will be used later in the report when total emission factors and national impact are estimated.

Instrumentation for measurement of sulfur oxides in the exhaust of internal combustion engines has not been developed to the same point as that for other common pollutants, so it has become more or less accepted practice to calculate sulfur oxide emissions based on fuel sulfur content. The assumption is usually made for convenience that all the sulfur oxidizes to SO_2, and thus the mass emission rate of SO_2 is taken to be 2.00 times the rate at which sulfur is entering the engine in the form of fuel (2.00 is the ratio of the molecular weight of SO_2 to the atomic weight of S). This technique is fairly accurate for 4-stroke engines (where substantially all the fuel is being burned), but it should be modified for 2-stroke engines to reflect the fact that a substantial fraction of the fuel is not being burned (that is, some of the fuel sulfur is being emitted without being oxidized). This modification is made by assuming that the fraction of fuel sulfur going to SO_2 is the same as the fraction of the fuel burned, which can be determined from hydrocarbon mass emissions. Emission rates will be calculated and included in section V, based on assumed fuel sulfur contents(10) of 0.043% by weight for the regular fuel used in small engines.

E. Measurement of Emissions During Transients

The reason for measuring emissions during transients is that they are not included implicitly in the other test procedures on which the small engines were operated, such as they are in procedures for automobile testing, for example. The goal of these measurements was not necessarily to determine mass emissions as a function of time, but rather to compare concentrations during transients to those for steady-state conditions which form the starting and ending points for the transients. The transient measurements were taken on three of the five engines, with the Briggs & Stratton 92908 excluded due to the absence of analog rpm readout, (although emissions were recorded during cold starts for this engine), and the Wisconsin S-12D excluded because its throttle was difficult to control.

To acquire emissions data from transients in a useful form, it was necessary to record engine rpm as a function of time. The recorder used for transients had four channels, so only three remained for concentration data; and the constituents chosen for analysis were hydrocarbons, CO, and NO. It should be noted here that concentration data for hydrocarbons were "wet", and that those for CO and NO were "dry". These CO and NO data during transients are the only concentration data in this report which are on a dry basis (insufficient data were acquired for conversion to wet basis), and they will be presented only in the form of graphs in Appendix C. These graphs depict engine rpm and concentration data as functions of time, and they will be discussed in section IV with the other emission results. It was necessary to draw the graphs because recorder chart traces for the NDIR instruments are not directly proportional to concentration, and this nonlinearity would have resulted in difficult-to-read scales had the charts been reproduced directly.

The graphical records given in Appendix C are the most representative of several runs made over each transient condition. Some of the transients were repeated three or four times, in order to get a good feel for the results, before a representative trace was chosen. The transient conditions run on each of the three engines included: a rapid deceleration from rated speed and no load to idle by closing the throttle; a rapid deceleration (or lug-down) from rated speed and full load to intermediate speed and full load by increasing the load; a rapid acceleration from intermediate speed and full load to rated speed and full load by decreasing the load; and a rapid acceleration from idle to high speed and no load by opening the throttle. Other conditions run on one or two engines included; a simultaneous rapid reduction of load and throttle to go from rated speed and full load to idle; an acceleration from intermediate speed and part load to (preset) full load at rated speed by opening the throttle; and a load change at essentially constant speed (throttle controlled by governor). Cold start transients were run on one engine to observe variation in emissions during engine warmup.

IV. EMISSIONS TEST RESULTS

Emissions data taken on the small engines during this study are given in complete form in the Appendixes. Appendix A contains data from the 13-mode tests, Appendix B contains data from the 9-mode tests and the special 30-mode tests on the Briggs & Stratton model 92908 engine, and Appendix C consists of graphical representations of emission concentrations during transients.

A. Gaseous Emissions

Data developed on the 9-mode procedure are summarized in Table 3, with either 2 or 3 runs averaged on each engine. These data are of limited usefulness for impact purposes, but from a characterization standpoint they are useful in verifying the effects of change in fuel-air ratio. As expected, hydrocarbons and CO were generally highest during the "rich" modes (4-6) and lowest during the "lean" modes (7-9), with the "lean best power" modes (1-3) falling in between. Again as expected, the trend in NO_x was the opposite of that for hydrocarbons and CO, but no strong variation in aldehyde emissions with fuel-air ratio could be observed. The additional step of converting the 9-mode data to a brake specific basis has not been taken, but power data are available in Appendix B should the brake specific numbers be required.

Data developed on the 13-mode procedure are treated in more detail, since they are considered more useful in both characterization and impact calculations. To begin, average mass emissions and brake specific emissions have been tabulated as functions of load and speed for each engine. Hydrocarbon data are given in Table 4, CO data in Table 5, NO_x data (as NO_2) in Table 6, and aliphatic aldehyde data (RCHO as HCHO) in Table 7. These tabular data could be plotted as rudimentary emission "maps", if so desired, but this step has not been taken for this report. The maps would be rather rough due to the small number of data points represented, and it would be recommended that considerably more data be acquired before attempting to construct maps.

The data in Tables 4 through 7 provide an indication of variation in emission rates with engine size and type, and all these runs were made with the carburetor adjusted for lean best power operation at rated speed. The procedure followed was to run 2 or more 13-mode tests using rated and intermediate speeds, then to run 1 test or more using "high intermediate" (2nd highest speed listed) and "low intermediate" (4th highest) speeds instead. This independence of runs added an unwanted variable, namely day-to-day changes in carburetor setting for lean best power operation, to the data. For some engines, the change was not significant, but for others it was. In summary, data scatter makes finer analysis of mode-by-mode emissions from the individual engines only marginally useful, so further analysis will be concentrated on composite (cycle) emissions and those averaged over the engines tested by type (4-stroke and 2-stroke).

TABLE 3. MASS EMISSIONS FROM SMALL ENGINES OPERATED ON THE 9-MODE PROCEDURE

Constituent	Engine	Average Mass Emissions in g/hr by Mode								
		1	2	3	4	5	6	7	8	9
HC	B&S 92908	32.7	30.7	17.4	48.3	41.4	17.7	26.2	27.5	15.1
	B&S 100202	20.3	10.4	13.0	25.9	19.4	17.7	16.6	9.28	12.8
	Kohler K482	144.	76.4	84.6	158.	86.4	95.6	124.	63.8	71.8
	Tec. AH520*	274.	137.	70.3	318.	181.	107.	248.	137.	89.1
	Wisc. S-12D	79.2	65.9	54.8	102.	93.0	74.6	62.4	53.0	33.6
CO	B&S 92908	365.	459.	84.9	876.	760.	236.	84.5	305.	56.3
	B&S 100202	244.	24.4	63.7	687.	292.	249.	93.5	18.8	37.4
	Kohler K482	3750.	1890.	1960.	4450.	1940.	2050.	2670.	1000.	1570.
	Tec. AH520*	319.	276.	157.	723.	569.	266.	75.4	93.3	139.
	Wisc. S-12D	2530.	2030.	1260.	3520.	2960.	1600.	1390.	1320.	618.
NO_x as NO_2	B&S 92908	16.6	7.99	3.64	3.85	4.74	3.05	35.7	10.8	6.19
	B&S 100202	48.4	23.2	2.55	21.0	14.2	0.96	59.2	21.6	2.30
	Kohler K482	55.8	30.8	3.32	38.5	25.7	2.96	109.	44.5	5.10
	Tec. AH520*	4.50	1.69	0.82	1.66	1.33	0.89	9.54	2.96	2.03
	Wisc. S-12D	39.4	9.51	3.40	22.0	6.56	2.92	78.9	21.0	4.34
RCHO as HCHO	B&S 92908	1.12	1.01	0.94	1.51	0.88	0.61	1.25	1.00	0.99
	B&S 100202	1.76	1.24	0.48	1.20	0.61	0.44	1.34	1.04	0.58
	Kohler K482	7.64	3.13	1.70	5.95	3.28	2.94	3.45	2.24	1.80
	Tec. AH520	3.03	2.08	1.32	2.92	1.88	1.38	3.40	2.48	1.34
	Wisc. S-12D	2.90	1.72	1.10	2.29	1.74	1.32	2.45	1.68	1.42

* Average of 2 runs at 4500 (rated) rpm and 1 run at 3600 rpm

TABLE 4. HYDROCARBON EMISSIONS* FROM SMALL ENGINES BY LOAD AND SPEED IN MASS RATES (g/hr) AND BRAKE SPECIFIC RATES (g/hphr)

		Mass Emissions, g/hr, by % Full Load					Brake Specific Emissions, g/hphr, by % Full Load			
Engine	Speed, rpm	0	25	50	75	100	25	50	75	100
B&S 92908	Idle(1730)	22.2	-------	-------	-------	-------	------	------	------	------
	2200	14.8	11.6	10.4	11.3	39.6	19.7	9.81	5.65	15.5
	2600	24.6	19.4	22.3	31.0	75.6	31.0	17.3	16.1	26.7
	3100	28.6	12.2	13.8	16.8	48.2	15.4	8.79	6.86	15.4
	3600	17.7	28.0	35.8	50.7	35.1	36.6	23.4	22.2	10.8
B&S 100202	Idle(1700)	20.0	-------	-------	-------	-------	------	------	------	------
	2200	16.9	12.1	16.0	21.9	22.1	22.0	15.2	14.1	10.8
	2600	12.6	12.0	16.2	21.2	12.3	16.7	12.1	10.8	4.76
	3100	13.4	8.86	19.0	25.3	19.6	9.84	11.5	10.8	6.64
	3600	4.18	5.48	15.8	10.0	11.2	6.28	5.10	4.51	3.75
**Kohler K482	Idle(1120)	301.	-------	-------	-------	-------	------	------	------	------
	1800	195.	94.5	110.	152.	483.	41.3	24.4	22.7	54.3
	2300	94.4	103.	113.	125.	148.	35.0	19.6	21.5	18.0
	3000	161.	93.6	81.3	103.	125.	26.1	11.6	9.81	8.99
	3600	120.	114.	125.	182.	234.	29.8	16.7	16.5	15.7
Tecumseh	Idle(3310)	78.4	-------	-------	-------	-------	------	------	------	------
AH 520	3500	74.8	102.	153.	208.	356.	211.	193.	191.	227.
	4500	80.6	105.	156.	211.	294.	230.	175.	176.	180.
Wisconsin	Idle(1090)	20.2	-------	-------	-------	-------	------	------	------	------
S-12D	1850	34.8	32.1	34.5	38.3	39.5	18.9	10.8	7.98	6.08
	2300	51.4	34.2	20.1	18.3	28.2	20.1	5.91	3.66	3.76
	3000	59.7	38.6	45.1	62.4	83.4	16.1	9.60	8.91	8.87
	3600	73.3	62.7	82.6	107.	119.	25.0	17.6	15.3	12.7

* Average Emissions for cases in which more than one run was made.

**Emissions from the test engine may be higher than typical for the model due to carburetor setting.

TABLE 5. CARBON MONOXIDE EMISSIONS* FROM SMALL ENGINES BY LOAD AND SPEED IN MASS RATES (g/hr) AND BRAKE SPECIFIC RATES (g/hphr)

Engine	Speed, rpm	Mass Emissions, g/hr, by % Full Load					Brake Specific Emissions, g/hphr, by % Full Load			
		0	25	50	75	100	25	50	75	100
B&S 92908	Idle(1730)	189.	-------	-------	-------	-------	------	------	------	------
	2200	23.4	9.50	6.58	6.42	727.	16.1	6.21	3.21	284.
	2600	301.	262.	299.	486.	852.	421.	233.	253.	294.
	3100	12.5	11.5	12.2	35.7	804.	14.6	7.77	14.6	257.
	3600	134.	347.	499.	860.	484.	461.	328.	380.	148.
B&S 100202	Idle(1700)	197.	-------	-------	-------	-------	------	------	------	------
	2200	219.	151.	200.	322.	358.	275.	190.	208.	175.
	2600	218.	166.	238.	566.	524.	229.	176.	286.	204.
	3100	203.	23.4	215.	726.	125.	26.0	130.	309.	42.4
	3600	20.6	24.7	61.2	132.	108.	28.3	39.8	59.8	36.4
**Kohler K482	Idle(1120)	547.	-------	-------	-------	-------	------	------	------	------
	1800	944.	1320.	1720.	2980.	5500.	576.	383.	444.	618.
	2300	910	1480.	1790.	1960.	3000.	508.	311.	307.	335.
	3000	1920.	2190.	1750.	2080.	2770	608.	250.	198.	199.
	3600	1970.	2080.	1990.	3460.	4710.	316.	312.	265.	539.
Tecumseh AH 520	Idle(3310)	137.	-------	-------	-------	-------	------	------	------	------
	3500	127.	280.	400.	487.	568.	576.	502.	446.	372.
	4500	241.	400.	472.	524.	642.	706.	530.	480.	390.
Wisconsin S-12D	Idle(1090)	72.7	-------	-------	-------	-------	------	------	------	------
	1850	482.	524.	537.	647.	916.	308.	168.	135.	141.
	2300	741.	556.	73.8	64.3	446.	327.	21.7	12.9	59.5
	3000	873.	841.	1260.	1720.	2440.	350.	269.	246.	259.
	3600	1540.	1560.	2550.	3490.	4450.	624.	543.	499.	474.

* Average Emissions for cases in which more than one run was made.

** Emissions from the test engine may be higher than typical for the model due to carburetor setting.

TABLE 6. OXIDES OF NITROGEN (NO_x) EMISSIONS* FROM SMALL ENGINES BY LOAD AND SPEED IN MASS RATES (g/hr) AND BRAKE SPECIFIC RATES (g/hphr)

Engine	Speed, rpm	Mass Emissions, g/hr, by % Full Load					Brake Specific Emissions, g/hphr, by % Full Load			
		0	25	50	75	100	25	50	75	100
B&S 92908	Idle(1730)	0.29	-------	-------	-------	-------	------	------	------	------
	2200	1.10	2.84	4.63	7.46	0.92	4.81	4.37	3.73	0.36
	2600	0.61	0.95	1.31	1.32	0.89	1.51	1.01	0.68	0.31
	3100	1.39	8.30	9.78	25.6	2.21	10.5	6.23	10.4	0.70
	3600	4.30	3.72	5.47	4.68	12.5	4.77	3.51	1.98	4.04
B&S 100202	Idle(1700)	0.15	-------	-------	-------	-------	------	------	------	------
	2200	0.19	1.33	6.04	7.51	17.9	2.42	5.75	4.85	8.74
	2600	0.61	2.40	8.25	6.40	12.8	3.35	6.08	3.24	4.96
	3100	0.69	9.33	15.2	7.88	58.0	10.4	9.21	3.35	19.7
	3600	3.14	9.58	20.7	32.0	54.0	10.9	13.4	14.3	18.1
Kohler K482	Idle(1120)	1.86	-------	-------	-------	-------	------	------	------	------
	1800	1.37	2.09	5.16	4.94	4.42	0.91	1.15	0.74	0.50
	2300	2.18	4.20	11.0	47.0	68.5	1.40	1.89	5.60	6.02
	3000	2.59	5.18	20.0	51.2	68.3	1.44	2.86	4.87	4.91
	3600	5.44	10.6	29.2	32.0	42.4	2.74	3.90	2.88	2.79
Tecumseh AH 520	Idle(3310)	0.45	-------	-------	-------	-------	------	------	------	------
	3500	0.42	0.66	0.89	1.31	2.58	1.36	1.14	1.22	1.73
	4500	0.92	1.16	1.38	1.64	2.38	2.00	1.56	1.38	1.48
Wisconsin S-12D	Idle(1090)	0.56	-------	-------	-------	-------	------	------	------	------
	1850	1.13	4.24	24.2	52.8	63.4	2.49	7.55	11.0	9.75
	2300	1.67	4.42	36.2	69.0	102.	2.60	10.6	13.8	13.6
	3000	3.40	8.21	19.1	36.0	40.7	3.42	4.06	5.15	4.33
	3600	3.21	5.42	8.33	8.71	15.5	2.17	1.77	1.24	1.65

* Average Emissions for cases in which more than one run was made.

TABLE 7. ALIPHATIC ALDEHYDE (RCHO) EMISSIONS* FROM SMALL ENGINES BY LOAD AND SPEED IN MASS RATES (g/hr) AND BRAKE SPECIFIC RATES (g/hphr)

Engine	Speed, rpm	Mass Emissions, g/hr, by % Full Load					Brake Specific Emissions, g/hphr, by % Full Load			
		0	25	50	75	100	25	50	75	100
B&S 92908	Idle(1730)	0.34	-------	-------	-------	-------	------	------	------	------
	2200	-------	-------	-------	-------	-------	------	------	------	------
	2600	0.55	0.47	0.54	0.53	0.78	0.76	0.42	0.28	0.27
	3100	-------	-------	-------	-------	-------	------	------	------	------
	3600	0.61	0.50	0.69	0.78	0.93	0.65	0.45	0.34	0.29
B&S 100202	Idle(1700)	0.23	-------	-------	-------	-------	------	------	------	------
	2200	-------	-------	-------	-------	-------	------	------	------	------
	2600	0.30	0.30	0.36	0.58	0.58	0.41	0.27	0.30	0.22
	3100	-------	-------	-------	-------	-------	------	------	------	------
	3600	0.50	0.63	0.74	0.70	0.90	0.73	0.48	0.32	0.30
Kohler K482	Idle(1120)	1.54	-------	-------	-------	-------	------	------	------	------
	1800	2.27	1.72	4.09	2.59	5.97	0.75	0.91	0.39	0.67
	2300	1.30	0.97	1.07	1.25	1.91	0.35	0.19	0.39	0.44
	3000	2.27	3.69	2.97	4.45	10.65	1.03	0.42	0.42	0.77
	3600	3.95	2.60	4.17	3.71	6.57	0.67	0.54	0.33	0.42
Tecumseh AH 520	Idle(3310)	0.86	-------	-------	-------	-------	------	------	------	------
	3500	0.94	1.17	1.40	1.64	2.72	2.42	1.76	1.51	1.80
	4500	1.27	1.38	1.58	1.96	2.63	2.47	1.79	1.64	1.62
Wisconsin S-12D	Idle(1090)	0.31	-------	-------	-------	-------	------	------	------	------
	1850	0.59	0.62	0.96	1.23	1.71	0.36	0.30	0.26	0.26
	2300	0.88	0.78	1.39	2.54	2.87	0.46	0.41	0.51	0.38
	3000	0.99	0.83	1.62	2.10	2.77	0.35	0.34	0.30	0.29
	3600	1.22	1.25	1.60	1.93	2.84	0.50	0.34	0.28	0.30

* Average Emissions for cases in which more than one run was made.

The 13-mode composite mass emissions and brake specific emissions are given in Table 8, including individual runs and averages for the 5 engines tested. The mode data were weighted according to the schedule shown in Table 2 to compute the composite results, and runs were made at two sets of speeds on 4 of the engines to provide a crude basis for constructing emission maps. A lower set of operating speeds was not practical for the Tecumseh AH520 because it had a rather narrow power band, and composite emissions for run 3 on the Wisconsin S-12D engine (basic data given in Appendix A, p. A-13) were not computed because the CO data for the run were not usable. The composite data are not extremely consistent, and the degree of variation seems to be characteristic of all the engines tested rather than just one or two of them. The average brake specific emissions for 4-stroke engines show reasonable consistency, however, with variation in NO_x over a range of 3-to-1 and variation in the other emissions of about 2-to-1.

The final analysis of the major 13-mode gaseous emissions data is to take averages of brake specific emissions over the 4-stroke engines (and list corresponding values for the single 2-stroke engine tested) at each speed/load condition. The results of this analysis are given in Table 9, and they represent the best estimate of variation in brake specific emissions with speed and load which can be constructed from the subject tests. The large differences in characteristic emissions from 2-stroke and 4-stroke engines are again apparent in these data. Had procedures been more highly developed at the time these data were acquired, power increments would probably have been 12.5% rather than 25%. It does not appear that the closer spacing would have improved understanding of emission patterns in the 25% to 100% load range, but no doubt the 12.5% load point would have been very interesting.

To provide better visualization of the average mode data, they have been graphed and appear as Figures 21 through 24. Figure 21 shows hydrocarbon emissions, and it uses a dual ordinate due to the order-of-magnitude difference in emissions from 2-strokes and 4-strokes. The reference arrows and different plotting symbols used for Figure 21 should eliminate confusion if the graph is examined carefully. It should be noted that percent of full load was chosen as the independent variable because the four speeds were not always the same for the 4-stroke engines. The more general speed classifications make it logical to use speed as a parameter.

Figure 22 shows CO emissions, with those from the 2-stroke engine being consistently higher. It is widely held that brake specific CO from 2-strokes should be equal to or lower than that from 4-strokes, so perhaps the subject comparison should be treated carefully until more data are available. It might be noted that minimum CO from 2-strokes tends to occur near rated speed, so the bias of the 13-mode procedure toward lower speeds (60%) may keep any CO advantage from showing up in composite

TABLE 8. SUMMARY OF 13-MODE COMPOSITE EMISSIONS RESULTS FOR SMALL ENGINES

			Composite Mass Emissions, g/hr				Composite Brake Specific Emissions, g/hphr			
Engine	Run	Rated/ Intermediate Speeds, rpm	HC	CO	NO_x	RCHO	HC	CO	NO_x	RCHO
B&S 92908	2	3600/2600	29.4	475.	3.22	0.51	25.8	417.	2.82	0.45
	3	3600/2600	32.6	381.	1.97	0.66	26.9	315.	1.63	0.55
	4	3600/2600	34.7	360.	3.55	0.56	28.4	295.	2.91	0.46
	5	2200/3100	19.3	153.	5.21	--	16.8	133.	4.53	--
	Avg.		29.0	342.	3.49	0.58	24.5	290.	2.98	0.49
B&S 100202	1	3600/2600	13.5	208.	10.6	0.61	11.7	181.	9.22	0.53
	2	3600/2600	11.8	199.	13.4	0.55	9.67	163.	11.0	0.45
	3	3100/2200	18.8	244.	9.95	--	17.4	226.	9.21	--
	Avg.		14.7	217.	11.3	0.58	12.9	190.	9.81	0.49
Kohler K482	2	3600/2300	122.	1840.	29.2	2.45	22.9	345.	5.49	0.46
	3	3000/1800	198.	1980.	13.7	3.61	43.1	429.	2.97	0.78
	4	3600/2300	136.	2010.	11.5	--	25.3	375.	2.13	--
	Avg.		152.	1940.	18.1	3.03	30.4	383.	3.53	0.62
Tec. AH520	1	4500/3500	176.	426.	0.96	1.58	232.	561.	1.26	2.07
	2	4500/3500	140.	291.	1.35	1.43	197.	410.	1.90	2.01
	Avg.		158.	358.	1.16	1.50	214.	486.	1.58	2.04
Wisc. S-12D	1	3600/2300	52.6	1250.	20.4	1.45	15.6	369.	6.04	0.43
	2	3000/1850	40.7	840.	20.4	1.13	12.7	262.	6.35	0.35
	Avg.		46.6	1040.	20.4	1.29	14.2	316.	6.20	0.39

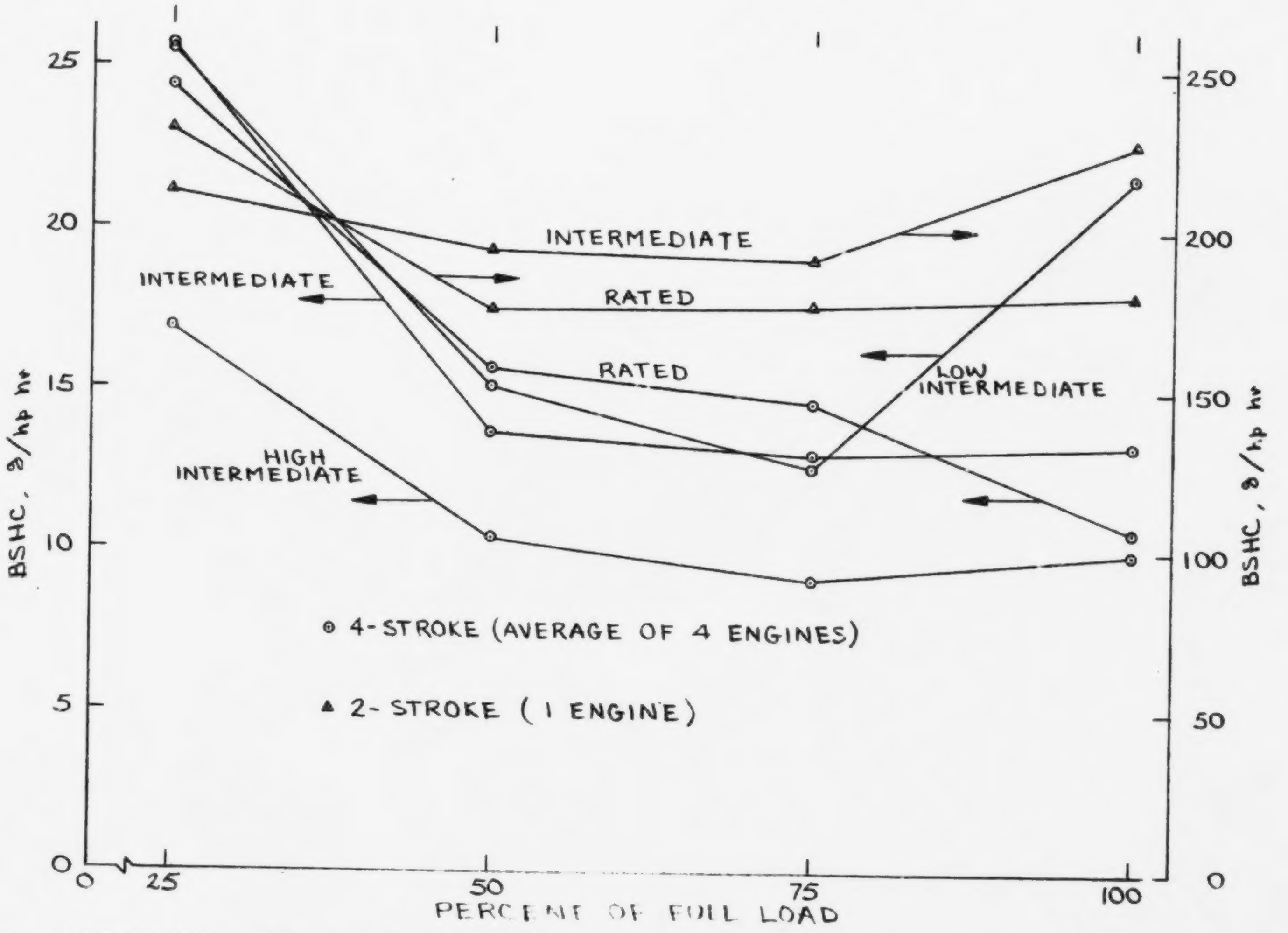

FIGURE 21. HYDROCARBON EMISSIONS FROM SMALL ENGINES AS FUNCTIONS OF LOAD AND SPEED

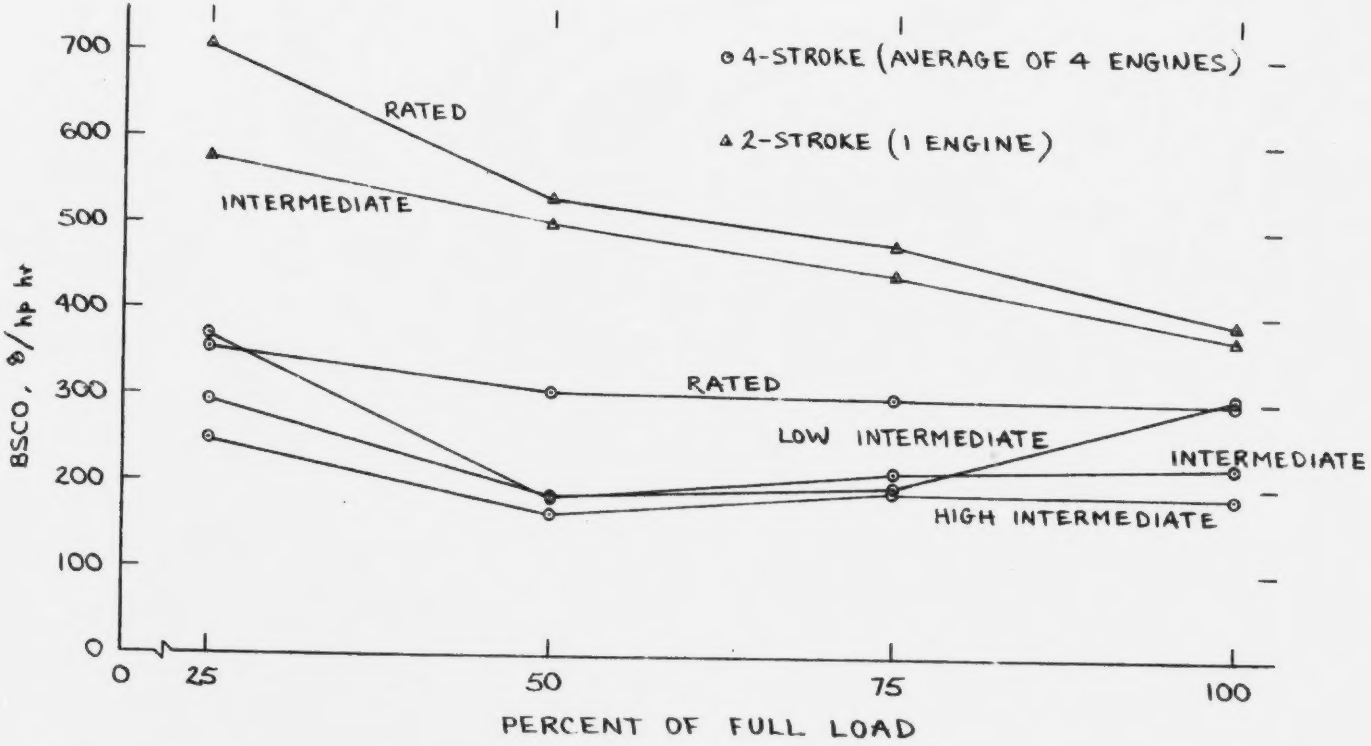

FIGURE 22. CO EMISSIONS FROM SMALL ENGINES AS FUNCTIONS OF LOAD AND SPEED

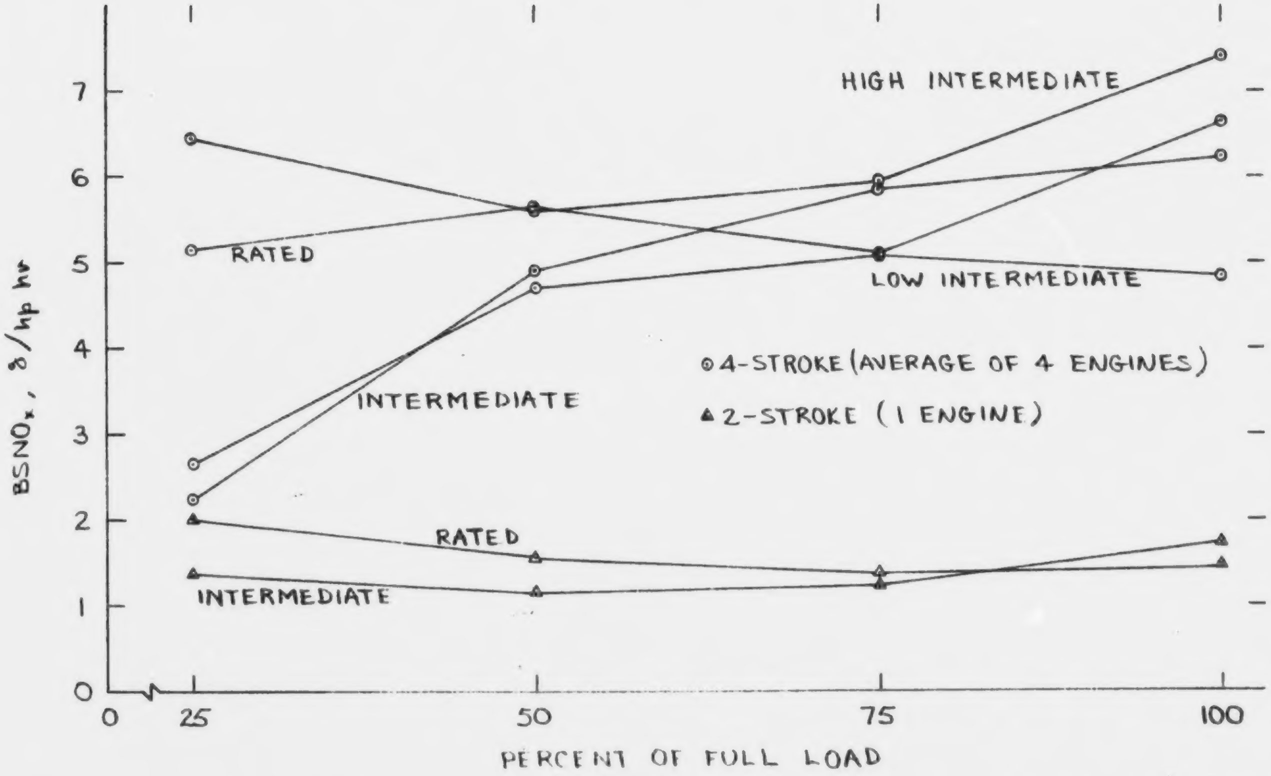

FIGURE 23. NO$_x$ EMISSIONS FROM SMALL ENGINES AS FUNCTIONS OF LOAD AND SPEED

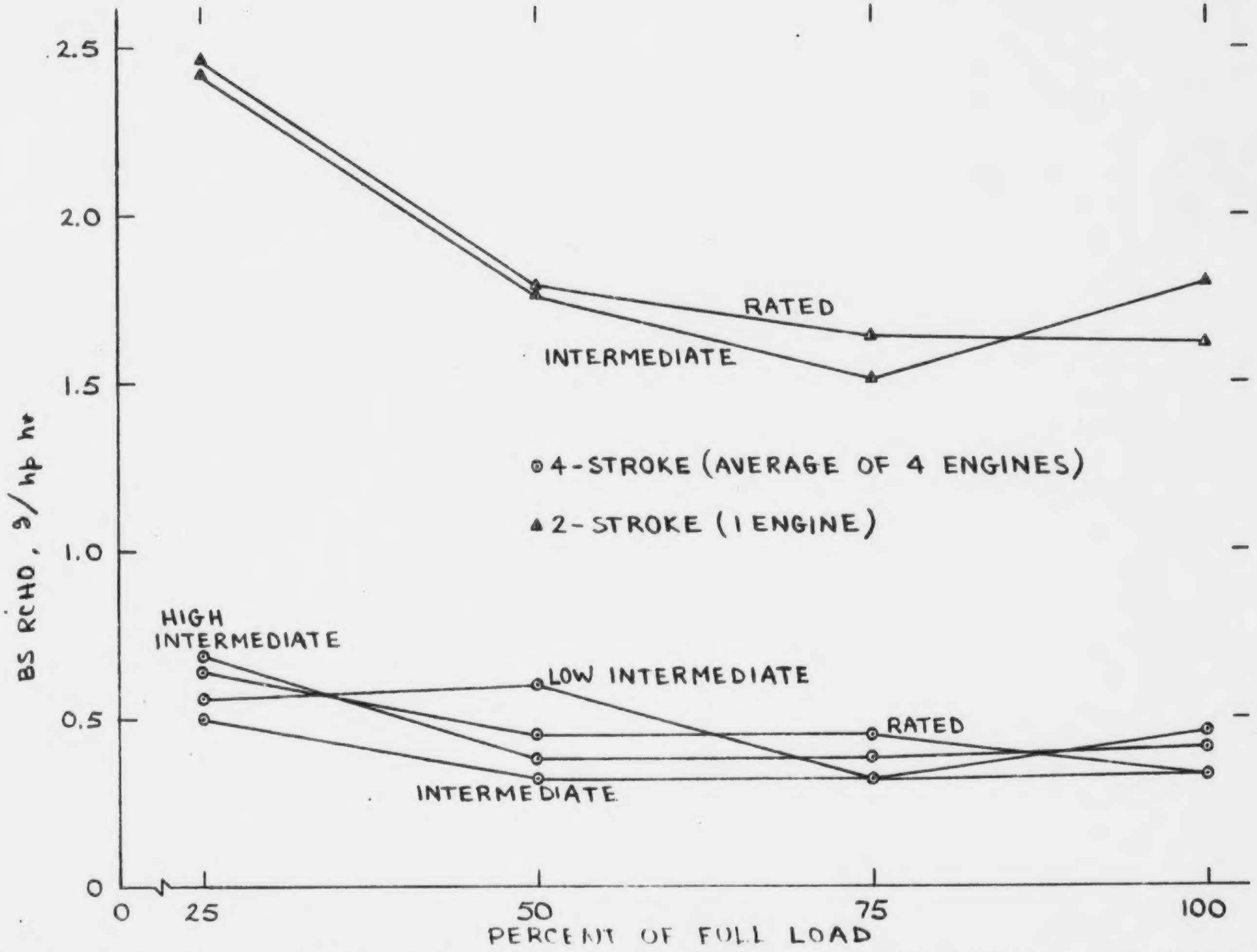

FIGURE 24. ALDEHYDE EMISSIONS FROM SMALL ENGINES AS FUNCTIONS OF LOAD AND SPEED

data. The particular engine tested, however, seemed to have higher CO emissions as engine speed increased, contrary to the common rule of thumb.

TABLE 9. AVERAGE MODE BRAKE SPECIFIC EMISSIONS FROM SMALL ENGINES

Constituent	Engine Speed	Average 4-Stroke Brake Specific Emissions (g/hp hr) at % Load				2-Stroke Brake Specific Emissions (g/hp hr) at % Load (1 engine)			
		25	50	75	100	25	50	75	100
HC	Low Inter.	25.5	15.1	12.6	21.7	----	----	----	----
	Intermed.	25.7	13.7	13.0	13.3	211.	193.	191.	227.
	High Inter.	16.9	10.4	9.10	9.98	----	----	----	----
	Rated	24.4	15.7	14.6	10.7	230.	175.	176.	180.
CO	Low Inter.	294.	187.	198.	304.	----	----	----	----
	Intermed.	371.	185.	215.	223.	576.	502.	446.	372.
	High Inter.	250.	164.	192.	189.	----	----	----	----
	Rated	357.	306.	301.	299.	706.	530.	480.	390.
NO_x as NO_2	Low Inter.	2.66	4.70	5.08	4.84	----	----	----	----
	Intermed.	2.22	4.90	5.83	6.22	1.36	1.14	1.22	1.73
	High Inter.	6.44	5.59	5.94	7.41	----	----	----	----
	Rated	5.14	5.64	5.10	6.64	2.00	1.56	1.38	1.48
RCHO as HCHO	Low Inter.	0.56	0.60	0.32	0.46	----	----	----	----
	Intermed.	0.50	0.32	0.32	0.33	2.42	1.76	1.51	1.80
	High Inter.	0.69	0.38	0.38	0.41	----	----	----	----
	Rated	0.64	0.45	0.45	0.33	2.47	1.79	1.64	1.62

The NO_x emissions depicted by Figure 23 show lower values for the 2-stroke engine than for the average of the 4-strokes, as expected. The relatively weak dependence on speed and load for 4-strokes is somewhat surprising, however, and may be due to inability of the carburetion systems to maintain relatively constant F/A over the range of operating conditions. This same cause may be associated with scatter in the other emissions data, as well. Aldehyde emissions, shown in Figure 24, were quite a bit higher for the small 2-stroke engine tested than for the 4-strokes. This same trend was observed during other tests on 2-stroke engines conducted under this project, so it comes as no surprise. In Figure 24, as in the others, any confusion which may exist regarding applicability of the parameters shown to the corresponding curves can be eliminated by reference to Table 9.

To complete the presentation of gaseous emissions data, Tables 10 through 14 contain average light hydrocarbon emissions from the small engines on a mode-by-mode wet concentration basis. Most of the data points represent averages of two or more runs, but some of the 13-mode data are from one run only. Consistency from run to run was reasonably good, although the freshness of the fuel had a considerable effect on butane emissions. Propane concentrations were uniformly low because little propane was present in the fuel, and because propane is not a common combustion product.

TABLE 10. AVERAGE LIGHT HYDROCARBON EMISSIONS
FROM A BRIGGS & STRATTON 92908 ENGINE

Data Taken During 13-Mode Tests with Mfr's.
Recommended Carburetor Setting

Engine Speed, rpm	Load	Wet Concentration by Species, ppm						
		CH_4	C_2H_6	C_2H_4	C_3H_8	C_2H_2	C_3H_6	C_4H_{10}
Idle (1710)	None	1180	52	405	5	954	143	78
2600	None	848	52	364	3	487	140	30
	25%	488	25	208	3	315	83	31
	50%	535	25	212	4	293	99	39
	75%	786	26	259	3	352	87	33
	100%	871	28	269	5	408	90	56
3600	None	373	64	409	3	309	164	20
	25%	363	43	283	4	270	112	37
	50%	560	46	249	5	319	119	39
	75%	832	26	274	3	367	98	26
	100%	497	29	241	5	298	108	36

Data Taken During 9-Mode Tests at Rated Engine rpm (3600)

Fuel-Air Mixture	Load	Wet Concentration by Species, ppm						
		CH_4	C_2H_6	C_2H_4	C_3H_8	C_2H_2	C_3H_6	C_4H_{10}
Lean Best Power	None	284	31	178	1	142	102	32
	50%	362	32	210	1	207	100	31
	100%	252	36	179	2	190	102	27
Rich	None	693	30	266	3	302	124	23
	50%	645	42	254	11	317	130	52
	100%	306	40	240	1	187	75	10
Lean	None	154	49	236	1	129	124	23
	50%	358	45	280	2	211	126	14
	100%	141	48	248	2	127	97	42

The application of the light hydrocarbon data for the purposes of this project is primarily determining the fraction of total hydrocarbons which could be classed as combustion products rather than unburned fuel. Such a determination could be useful in estimating the overall reactivity of the exhaust hydrocarbons, if desired. Since butane is almost entirely an unburned fuel constituent, and since propane is present in such small amounts, the remaining analysis will concentrate on only five compounds (methane, ethane, ethene, acetylene, and propene). The mole percentages of total hydrocarbons (on a per carbon atom basis) which are actually light hydrocarbon combustion products are given in Table 15. Some other products of combustion having higher molecular weights are undoubtedly present, but the analysis used for this project could not measure them. Most studies on exhaust hydrocarbon composition, however, indicate that a large percentage of heavier hydrocarbons are in fact unburned fuel. Consequently, the compounds analyzed probably give a good indication of the level of combustion products compared to total hydrocarbons.

TABLE 11. AVERAGE LIGHT HYDROCARBON EMISSIONS FROM A BRIGGS & STRATTON 100202 ENGINE

Data Taken During 13-Mode Tests with Mfr's. Recommended Carburetor Setting

Engine Speed, rpm	Load	Wet Concentration by Species, ppm						
		CH_4	C_2H_6	C_2H_4	C_3H_8	C_2H_2	C_3H_6	C_4H_{10}
Idle (1680)	None	1130	58	438	6	1130	140	58
2600	None	523	36	200	3	352	90	22
	25%	320	28	202	2	286	72	14
	50%	167	18	110	1	128	50	10
	75%	300	28	202	1	230	90	16
	100%	324	20	234	5	333	108	60
3600	None	91	25	119	1	114	42	6
	25%	92	32	140	1	110	50	12
	50%	74	22	127	0	96	52	8
	75%	114	16	99	0	110	50	15
	100%	108	31	129	0	91	60	26

Data Taken During 9-Mode Tests at Rated Engine rpm (3600)

Fuel-Air Mixture	Load	Wet Concentration by Species, ppm						
		CH_4	C_2H_6	C_2H_4	C_3H_8	C_2H_2	C_3H_6	C_4H_{10}
Lean Best Power	None	154	24	137	0	100	67	10
	50%	78	21	126	1	80	57	8
	100%	89	22	106	0	89	37	4
Rich	None	230	20	145	0	168	70	10
	50%	195	28	144	1	141	77	12
	100%	267	32	184	2	78	84	14
Lean	None	106	22	128	0	90	59	9
	50%	40	12	112	1	56	45	3
	100%	261	43	243	0	172	92	14

As expected, the percentage of total hydrocarbons present as combustion products is substantially higher for 4-stroke engines than for the 2-stroke engine, due to the comparatively large amount of fuel being short-circuited in the 2-stroke engine. The concentrations of these five compounds were similar for both types of engines, however, but the butane

TABLE 12. AVERAGE LIGHT HYDROCARBON EMISSIONS FROM A KOHLER K482 ENGINE

Data Taken During 13-Mode Tests with Mfr's. Recommended Carburetor Setting

Engine Speed, rpm	Load	Wet Concentration by Species, ppm						
		CH_4	C_2H_6	C_2H_4	C_3H_8	C_2H_2	C_3H_6	C_4H_{10}
Idle (1130)	None	3130	207	1680	9	2140	467	295
1800	None	2660	178	1390	6	1210	197	67
	25%	1200	22	279	3	598	77	17
	50%	703	56	208	6	293	49	17
	75%	978	47	375	6	813	65	27
	100%	3000	29	413	7	938	75	39
2300	None	635	381	275	3	656	112	24
	25%	802	20	197	1	1890	74	19
	50%	3180	17	167	1	236	62	27
	75%	256	59	19	1	134	86	21
	100%	170	19	124	1	96	61	9
3000	None	969	63	405	3	969	162	44
	25%	509	23	207	3	302	110	22
	50%	352	27	207	3	188	96	13
	75%	590	63	299	3	204	77	14
	100%	404	49	207	2	197	78	11
3600	None	4970	33	257	2	882	105	15
	25%	2790	33	224	1	246	121	19
	50%	295	29	169	1	155	87	10
	75%	4080	26	2310	1	297	112	25
	100%	1630	20	190	2	216	79	10

Data Taken During 9-Mode Tests at Rated Engine rpm (3600)

Fuel-Air Mixture	Load	Wet Concentration by Species, ppm						
		CH_4	C_2H_6	C_2H_4	C_3H_8	C_2H_2	C_3H_6	C_4H_{10}
Lean Best Power	None	436	16	138	1	178	84	20
	50%	337	29	203	1	173	95	11
	100%	736	45	186	1	372	113	22
Rich	None	408	22	195	1	198	83	11
	50%	306	22	146	1	194	102	24
	100%	647	35	275	2	537	110	15
Lean	None	339	20	161	2	176	86	26
	50%	312	46	166	1	104	51	7
	100%	422	25	172	2	272	105	28

concentrations (reflecting unburned fuel concentrations) were about 10 times higher for the 2-stroke engine than for the 4-strokes. The relative concentrations of compounds by category is also interesting, with paraffinic compounds highest, followed in order by olefins and the only alkyne measured (acetylene).

B. Smoke Emissions (2-stroke engine only) and Particulate Emissions

Smoke emitted by the Tecumseh AH520 type 1448 engine, a small 2-stroke, was measured using the PHS full-flow smokemeter. Before going into the numerical results by mode, some idea of the appearance of smoke emitted by the engine can be gained by examining Figures 25 through 28. In numerical order, these photographs show smoke which registered 2%, 3%, 5%, and 6% opacity on the smokemeter's recorder

TABLE 13. AVERAGE LIGHT HYDROCARBON EMISSIONS FROM A TECUMSEH AH520 ENGINE

Data Taken During 13-Mode Tests with Mfr's. Recommended Carburetor Setting

Engine		Wet Concentration by Species, ppm						
Speed, rpm	Load	CH_4	C_2H_6	C_2H_4	C_3H_8	C_2H_2	C_3H_6	C_4H_{10}
Idle (3310)	None	412	71	280	4	406	233	203
3500	None	211	66	332	4	429	180	174
	25%	258	46	242	4	204	179	232
	50%	300	31	186	4	214	127	220
	75%	306	48	224	18	193	181	245
	100%	230	38	238	2	114	216	374
4500	None	641	115	428	8	364	258	136
	25%	350	60	256	6	455	252	268
	50%	350	68	288	34	354	212	210
	75%	219	40	166	24	162	156	250
	100%	273	48	295	3	128	210	232

Data Taken During 9-Mode Tests at Rated Engine rpm (4500)

Fuel-Air		Wet Concentration by Species, ppm						
Mixture	Load	CH_4	C_2H_6	C_2H_4	C_3H_8	C_2H_2	C_3H_6	C_4H_{10}
Lean Best Power	None	240	92	346	12	77	290	174
	50%	245	87	346	6	88	256	101
	100%	312	114	397	74	366	522	222
Rich	None	242	25	143	13	190	180	174
	50%	355	42	201	7	210	267	226
	100%	332	60	309	5	206	175	64
Lean	None	230	148	610	10	73	420	146
	50%	190	106	382	10	108	283	131
	100%	174	83	308	6	74	188	114

TABLE 14. AVERAGE LIGHT HYDROCARBON EMISSIONS FROM A WISCONSIN S-12D ENGINE

Data Taken During 13-**Mode Tests with** Mfr's. Recommended Carburetor Setting

Engine Speed, rpm	Load	Wet Concentration by Species, ppm						
		CH_4	C_2H_6	C_2H_4	C_3H_8	C_2H_2	C_3H_6	C_4H_{10}
Idle (1070)	None	184	37	175	3	153	92	42
1850	None	613	49	296	5	469	127	32
	25%	333	23	168	1	211	81	23
	50%	271	22	173	1	152	75	11
	75%	201	18	140	0	101	79	12
	100%	251	20	140	0	108	76	13
2300	None	598	55	357	7	381	154	25
	25%	347	37	214	2	189	103	15
	50%	225	27	162	1	164	70	7
	75%	123	15	116	1	69	32	4
	100%	157	20	135	1	70	52	5
3000	None	554	62	396	3	384	181	30
	25%	371	37	227	1	196	104	18
	50%	373	28	214	1	189	113	18
	75%	311	30	185	0	126	91	20
	100%	433	20	191	0	188	95	16
3600	None	587	49	367	3	404	152	20
	25%	455	36	251	3	226	110	19
	50%	520	21	210	1	236	100	13
	75%	570	22	220	1	235	98	21
	100%	647	17	225	4	250	94	14

Data Taken During 9-Mode Tests at Rated Engine Speed (3600)

Fuel-Air Mixture	Load	Wet Concentration by Species, ppm						
		CH_4	C_2H_6	C_2H_4	C_3H_8	C_2H_2	C_3H_6	C_4H_{10}
Lean Best Power	None	441	25	209	2	170	95	15
	50%	377	22	196	0	179	88	12
	100%	531	50	194	4	347	137	24
Rich	None	420	20	208	1	213	98	52
	50%	614	30	246	2	286	110	24
	100%	253	20	140	0	109	76	14
Lean	None	131	28	128	1	110	64	26
	50%	424	20	187	0	184	92	15
	100%	349	34	208	0	141	102	22

TABLE 15. SUMMARY OF LIGHT HYDROCARBON ANALYSIS FOR SMALL ENGINES

	Mole % of Total Hydrocarbons (ppmC) as Several Compounds					
Compound	B&S 92908	B&S 100202	Kohler K482	Wisc. S-12D	Avg. four 4-strokes	Tecum. AH520
CH_4	7.9	7.4	8.7	7.2	7.8	0.9
C_2H_6	9.8	13.5	10.3	7.9	10.4	1.6
C_2H_4	7.0	10.9	7.2	8.7	8.4	1.4
C_2H_2	0.7	1.9	1.4	1.3	1.3	0.4
C_3H_6	4.1	6.3	3.9	6.0	5.1	1.6
Total	29.5	40.0	31.5	31.1	33.0	5.9

trace while the pictures were being taken. This white smoke, which probably consists mainly of oil droplets, seems more visible for a given opacity value than black smoke is. Two factors which help to account for the difference are that white smoke exhibits much stronger "forward" scattering than black smoke does, and that a given opacity level of white smoke may contain a substantially higher concentration of particles than an equivalent opacity level of black smoke(11). The greater visibility may also be due partially to greater contrast with the background than would be the case for black smoke.

In scrutinizing the opacity values attached to the photos and those given in tabular form later, it should also be noted that they are based on a plume issuing from a 1 inch diameter stack. For comparison, smoke measurements taken on diesel engines are usually on plumes issuing from stacks 2 inches to 5 inches in diameter. During the smoke measurements (as well as the gaseous emissions tests), the Tecumseh engine was operated on a fuel mixture of 16 parts gasoline to 1 part oil (240 ml oil per gallon gasoline). The particular oil used was Harley-Davidson SAE 40 2-stroke engine oil, chosen because it was available when needed, not because of assumed greater applicability to the engine under test than other oils. Average opacity data are given in Table 16 for a number of conditions, and the LBP data were averaged over both 13-mode and 9-mode operation. The fuel/air ratio seemed to have a significant effect on smoke, with richer mixtures consistently producing higher opacity. The effects of engine speed and load, however, appeared to be mixed.

Data on particulate emissions from all the small engines are given in Table 17. They display somewhat more scatter than the data for other categories (which was acquired later) due to both instability of engine operation and the lack of some detail refinements made to the sampler and the technique in the interim. The data in general do not seem to depend

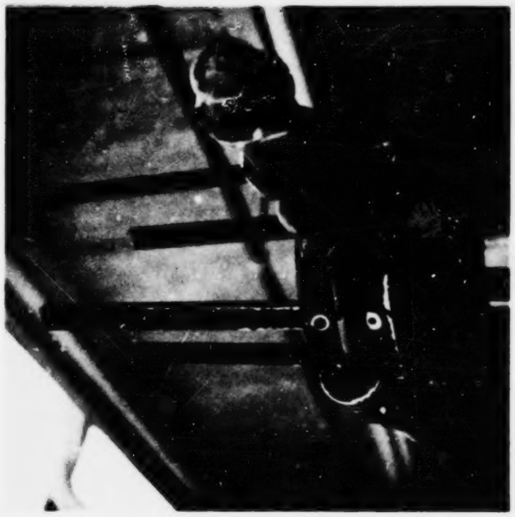

Figure 25. 2% Opacity Smoke from Tecumseh 2-stroke Engine

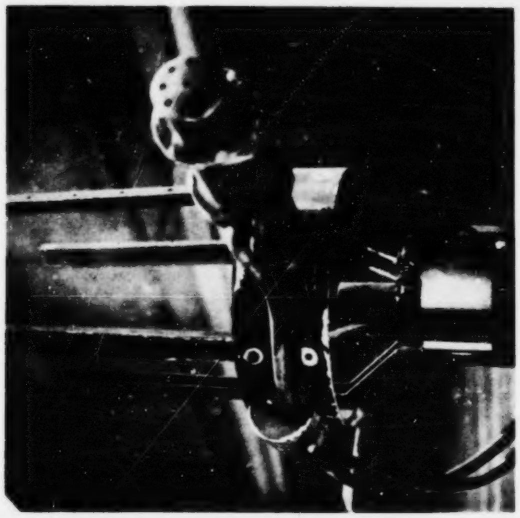

Figure 26. 3% Opacity Smoke from Tecumseh 2-stroke Engine

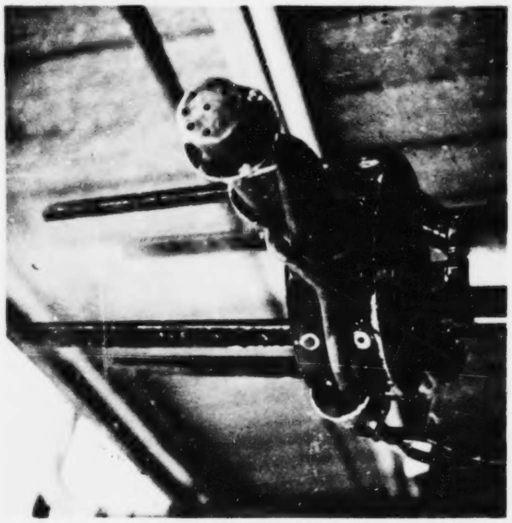

Figure 27. 5% Opacity Smoke from Tecumseh 2-stroke Engine

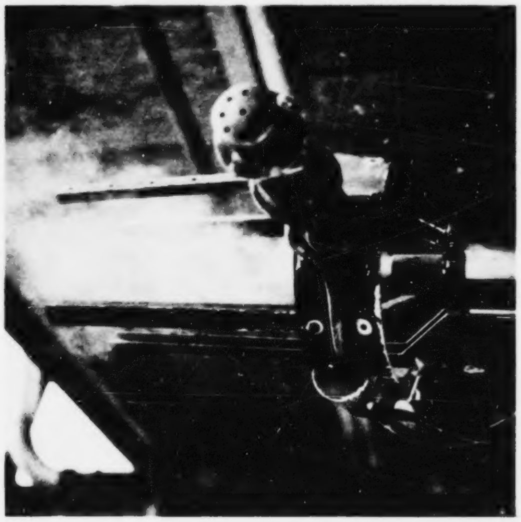

Figure 28. 6% Opacity Smoke from Tecumseh 2-stroke Engine

TABLE 16. AVERAGE SMOKE OPACITY FROM A TECUMSEH AH520 2-STROKE ENGINE, 1-INCH DIAMETER PIPE

F/A Mixture	Engine Speed, rpm	% Opacity at % Max. Load 0	50	100
LBP	3500	5.8	3.5	3.5
	4500	2.7	3.7	4.5
Rich	3500	6.5	5.5	6.0
	4500	6.2	4.2	5.8
Lean	3500	1.5	2.0	2.5
	4500	1.8	1.8	2.8

strongly on engine speed, but a positive relationship between power output and particulate concentration does seem to exist.

The results for the 4-stroke engines are fairly consistent, with the single vertical-crankshaft engine (Briggs & Stratton 92908) a little higher than the others. The 2-stroke emitted particulate at a considerably higher rate, however, presumably due to the presence of lubricating oil droplets in the exhaust. Most of the filters used for collecting particulate from the 4-strokes were colored a tan or light brown color by the exhaust (they were originally white), but the exhaust from the 2-stroke engine colored the filters a dull yellow. Data on the small engines correlate quite well with those acquired on other types of 2- and 4-stroke engines tested under this project, including motorcycles and industrial engines.

C. Emissions During Transients

The reason for measuring emissions during transients is to determine whether or not they exceed steady-state emissions to such an extent that they could be significant to the overall emissions from small engines. It is generally accepted that transient conditions make up only a relatively small fraction of the total operating time of small engines, so to be significant, an excursion would have to be considerably outside normal values for steady-state modes.

Graphs depicting small engine transient emissions (HC on a wet basis, CO and NO on a dry basis) are given in Appendix C. It can be assumed that engine rpm, load, and emissions are constant (stabilized) to the left and right of the time intervals over which the graphs are drawn. Note that on most of these plots there is a measurable lag between change in engine operation and a corresponding change in emissions. This time lag can be attributed to recorder and instrument response, residence time

TABLE 17. PARTICULATE EMISSIONS FROM SMALL UTILITY ENGINES

Engine	Condition		Individual Results, mg/SCF Exhaust						Average
	rpm	Load	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	mg/SCF
B&S 92908	1700	None	2.39	2.11	2.05	1.84	--	--	2.10
	3000	None	3.18	2.64	5.65	3.55	3.37	--	3.68
	3000	Full	3.68	2.97	5.99	4.96	3.58	--	4.24
B&S 100202	1700	None	1.77	2.29	2.08	--	--	--	2.05
	2200	None	1.62	2.42	2.22	--	--	--	2.09
	2200	Full	1.80	1.41	3.07	--	--	--	2.09
	2600	None	0.46	0.76	--	--	--	--	0.61
	2600	Full	1.88	1.21	2.84	--	--	--	1.78
	3100	None	1.43	2.33	--	--	--	--	1.88
	3100	Full	1.71	1.89	--	--	--	--	1.80
	3600	None	1.56	3.79	--	--	--	--	2.68
	3600	Full	2.54	1.02	2.33	--	--	--	1.76
Kohler K482	1600	None	2.09	2.90	2.66	--	--	--	2.55
	1600	Full	1.90	1.80	--	--	--	--	1.85
	2300	None	1.10	1.81	--	--	--	--	1.46
	2300	Full	2.93	1.82	--	--	--	--	2.38
	3000	Half	0.92	0.44	0.62	0.39	--	--	0.59
	3000	Full	3.95	2.45	1.91	1.64	3.27	--	2.64
	3300	None	0.61	0.39	0.50	0.50	--	--	0.50
	3600	Full	1.76	0.85	--	--	--	--	1.31
Tecumseh AH520	3300	None	20.3	26.1	40.9	30.1	31.9	--	29.9
	3500	Half	31.1	31.0	35.5	--	--	--	32.5
	3500	Full	46.4	61.0	48.7	60.4	--	--	54.1
	4500	None	22.3	21.7	24.5	--	--	--	22.8
	4500	Half	26.7	27.1	22.7	--	--	--	25.5
	4500	Full	30.1	40.0	31.1	26.5	--	--	31.9
Wisconsin S-12D	1150	None	0.94	0.87	1.75	1.49	1.16	0.88	1.18
	1850	None	0.35	1.89	0.62	0.56	--	--	0.86
	1850	Full	3.13	1.28	--	--	--	--	2.20
	2300	None	0.88	1.45	0.81	1.09	--	--	1.06
	2300	Half	1.04	2.25	--	--	--	--	1.64
	2300	Full	2.41	1.76	--	--	--	--	2.08
	3000	None	1.30	1.73	0.63	1.40	--	--	1.24
	3000	Full	1.74	2.31	--	--	--	--	2.02
	3600	None	1.63	1.82	0.98	--	--	--	1.48
	3600	Half	0.72	1.49	--	--	--	--	1.10
	3600	Full	1.13	1.55	--	--	--	--	1.34

in the sample lines, and time for the gases to come to equilibrium in the exhaust "mixing chamber". These contributions to the time lag are listed in the assumed order of increasing importance.

Although some definite excursions do occur in the graphs, most of them do not represent a total amount of emissions (perhaps expressed as average concentration above the line connecting initial and final values, multiplied by the peak duration) which would affect the overall picture very much. Unless it is shown that transients constitute an unexpectedly large percentage of operating time by some subsequent study, they can probably be neglected for calculation of emissions impact.

The last two graphs in Appendix C, Figures C-20 and C-21, show emissions during a cold start and idle for the Briggs & Stratton 92908 lawnmower engine. The ambient temperature was somewhat lower when run CS1 (upper) was conducted (75° F) than when run CS2 was conducted (90° F), which probably accounts for part of the difference in the two curves. These graphs show that the engine warms up rapidly after starting (even at slow idle), and this fact plus the relative infrequency of cold starts and the moderate excursions mean that cold starts probably have little significance in overall small engine emission levels. It is likely that many other air-cooled engines such as motorcycle engines, would exhibit the same sort of rapid warmup, making cold starts relatively unimportant.

V. ESTIMATION OF EMISSION FACTORS AND NATIONAL IMPACT

To determine emission factors for small engines individually, mass emissions data based on an assumed operating cycle are required. Extending available data to the population of small engines further requires knowledge of the breakdown of the population according to size and type. Estimation of national impact depends not only on emission rates, but also on total engine population and average annual usage. The type of analysis described here results in factors and estimates on a brake specific basis. It is not considered reasonable to attempt an analysis based on fuel consumed, since fuel used in small engines is largely sold with automotive fuels and thus cannot be quantified.

A. Development of Emission Factors

The engines tested in the small engine part of the project were chosen on the basis of manufacturer's recommendations, an assessment of current small engine market as given in several sources(12, 13, 14, 15), and a desire to represent to some extent the size range of currently available small engines. The engine choices were also made to coincide in part with engine models tested at the Bureau of Mines Bartlesville Research Station in a cooperative program with the SAE Small Engine Subcommittee(1). Each of the engines is probably used in a variety of ways, although records on the end uses of engines are difficult to find.

The Briggs & Stratton 92908 is used primarily on walking rotary lawnmowers, and in that application it is probably the single most popular small engine in use nationwide. The Briggs & Stratton 100202 engine is typical of engines used on small electric generators, compressors, pumps, reel-type lawnmowers, and minibikes (although Briggs & Stratton generally does not supply engines to manufacturers for minibike use). The Kohler K482 is typical of engines used on portable generators and mobile refrigeration units. The Tecumseh AH520 Type 1448 is used primarily on snow throwers, and the Wisconsin S-12D is typical of engines used in garden tractors, portable generators, and other applications. The engines tested are widely used, they include products of several manufacturers, and they are varied regarding size and type, but they do not represent a statistical sample of small engines used in the United States. This contract is not intended to gather baseline data on the entire category of small engines, but rather to make a comprehensive study of a few engines.

The category of engines in question here includes household, lawn and garden, industrial, agricultural, and recreational applications of small 2-stroke and 4-stroke gasoline-fueled utility engines. The category does not include motorcycles, outboard motors, chain saws, snowmobiles, or ATV's. The category does include minibikes except those powered by motorcycle engines.

Duty cycles of small engines are as varied as their applications, so this is an area which calls for a sound estimate based on the best available information or the alternative large research effort. The concepts of duty cycles, load factors, and test procedures, while certainly not identical, are all tied together closely when it comes to emissions measurements. Ideally, a separate duty cycle could be developed for each engine application by monitoring speeds and loads on a large sample of engines during typical operation, but this task has not yet been undertaken. For the purposes of the present analysis, one test procedure which approximates widely-encountered duty cycles should be sufficient. Many small engines, perhaps the numerical majority, are of the vertical-crankshaft type, rated from 3 to 3.5 hp, and used primarily on rotary lawnmowers. This application must be given strong consideration in determining an average duty cycle and load factor, and unlike most of the other applications, some information is available on the load factor involved in mowing grass.

Briggs & Stratton Corporation conducted a series of tests to determine power required for grass-cutting by first measuring fuel consumed during the mowing operation and then correlating engine power output with fuel consumption by dynamometer operation. This procedure showed that, on the average, about one hp is used in cutting grass(20). For engines rated at 3 to 4 horsepower which will probably produce 85% of rated power at normal ambient conditions, the one hp output means a load factor of 30% to 40%. Maximum crankshaft speeds in rotary mower application are frequently limited by safety considerations, especially when the blade exceeds 20 inches in length. For a 22 inch mower, for example, maximum governed speed would generally be set at 3300 rpm or less to prevent blade tip speed from exceeding 19,000 feet per minute, a generally-accepted maximum. Crankshaft speed and power output can be relatively steady if the grass density and length remain constant and if the ground is even, but power or speed or both will change if the other factors do. Except for relatively light grass on flat ground, speed and load can be expected to vary to some extent.

Some of the remaining applications of small engines, such as pumping, electric power generation, refrigeration, and blower service are characterized by constant-speed, constant-load operation at medium to high power levels. The manufacturers of small engines generally do not recommend sustained operation of their products at more than 80 or 85% of rated power, and in most cases manufacturers who use small engines in their end products do not count on the engines for more than 50 to 60% of rated power for continuous operation. Other applications, such as recreational vehicles, garden tractors, and motortillers make use of a variety of engine speeds and loads, and it is difficult to say what a fair load factor or operating sequence might be.

While it is not obvious just what the perfect duty cycle and test prodecure for small engines should be, it is obvious that operation only at rated speed does not represent real operation of most small engines. It seems reasonable that a test procedure encompassing a range of speeds and loads is more representative of the real situation, and so mass emissions values generated during operation on the modified EMA 13-mode cycle will be used in developing factors and estimates. That is, all the data generated during 13-mode runs will be used including runs with revised speeds (or "mapping" runs), but the 9-mode data from this program and from the SAE tests will not be used. Another reason for this choice is that the 40% load factor inherent in the EMA-type calculations seems much more reasonable than the over-50% factor assumed by the writers of SAE paper 720198 (that is, the emissions numbers used by the writers were generated while the engines were producing 50-70% of rated power).

As part of the test program emissions from several of the small engines were measured under transient conditions. These measurements showed that, in general, emissions during transients changed quite smoothly between values expected during steady-state runs at the starting and ending conditions. Some of the measurements showed a "hump" or a brief excursion of unexpectedly high concentrations of CO and/or hydrocarbons during the transient, but these excursions generally did not last long enough to become really significant in the overall picture. A complicating factor here was the presence of the exhaust mixing chamber, which undoubtedly tended to prolong the indicated emissions changes for the smaller engines. The same general comments apply to cold starts for small engines, that is, emissions may be outside normal limits briefly, but not to so great an extent that the overall emissions are altered significantly by the cold start. It should also be recognized that small air-cooled engines require a far shorter time to achieve normal operating temperature than do automotive powerplants, due to the absence of water jacketing and much smaller overall bulk. For the purposes of this project, then, emissions during transients will not be considered in developing factors.

In the raw data on small engine emissions, both formaldehyde (HCHO) and total aliphatic aldehyde (RCHO) concentrations are reported. Since the latter concentration value includes the former, it has been decided to use the RCHO concentration and the molecular weight of formaldehyde to arrive at mass-based aldehyde emissions. The reason for this procedure is that not all the structures of the molecules are known, so a molecular weight per carbonyl group must be assumed in order to convert from concentration to mass. When mass emissions are presented, then, RCHO will be given "as HCHO" in much the same way as NO_x is given "as NO_2."

The report on small engine tests conducted by the Bureau of Mines(1) has been reviewed in some detail, and it appears that raw data from that study agree quite well with raw data generated under this contract for those modes which can be compared directly. It is difficult to utilize some of the data in the Bureau of Mines report because the mid- and low-power points used for the smaller engines are not the same as those used in tests under this contract, and because only the single 3600 rpm speed was used. In addition, the lean and rich off-design conditions specified in the SAE small engine emissions measurement procedure are useful for research, but not for characterization, so two-thirds of the Bureau of Mines data and the same fraction of the SAE procedures conducted in the subject program cannot be used directly here. In order to make certain that engines tested under the subject contract were typical, emissions measured under conditions directly comparable to some of those used in the Bureau of Mines tests were calculated in terms of g/rated hp hr and compared to the earlier results(1,2). In most cases agreement was quite good, with the engines tested under this contract falling within the range reported for similar engines in the Bureau of Mines-SAE work.

For the purpose of determining emission factors, each of the three engine groups was assumed to be composed of test engines in different proportions. It was assumed that the lawn and garden/4-stroke category was made up of 90% Briggs & Stratton 92908 engines and 10% Briggs & Stratton 100202 engines; that the lawn and garden/2-stroke category was entirely Tecumseh AH520 Type 1448 engines; and that the miscellaneous/4-stroke category was composed of 10% B & S 92908, 14% Wisconsin S-12D, 74% B & S 100202, and 2% Kohler K482 engines. The composition estimates were made on the basis of limited production and sales information, so their accuracy is questionable, but emissions from the test engines were similar enough to make the impact estimates relatively insensitive to category composition. All the factors were derived as explained above except that the NO_x factor for the Briggs & Stratton 100202 engine was changed from 9.81 to 4.65 for computation purposes due to the atypical lean mixture this particular engine seemed to prefer (which caused high NO_x emissions). The factor was altered by correcting it to values which correspond to the "rich" portion of the 9-mode tests rather than the "lean best power" carburetor setting used in 13-mode tests. This change is well justified by both the Bureau of Mines data and the information developed under this contract, and is consistent with the idea that emission factors based on small samples should be conservative.

Particulate emissions from small engines were measured using an experimental dilution-type particulate sampler, but due to considerable scatter present in the data and a relatively small backlog of experience with the instrument, care must be taken not to overstate the accuracy which has been achieved. The engines were not operated on a fixed test procedure, primarily because the number of repetitions of each condition considered necessary would have made the time required prohibitive.

Within this framework, then, 2.5 mg/SCF exhaust for small 4-stroke engines and 25 mg/SCF exhaust for small 2-stroke engines seem to be reasonable estimates based on available data. In order to relate exhaust volume to some more usable term, exhaust mass generated during the modified EMA 13-mode tests was converted to SCF/hr (assuming that the exhaust molecular weight equalled that of air). These volume rates were then divided by the weighted power output to determine volume of exhaust per unit of work produced in SCF/hp hr, and weighted means of 175 SCF/hp hr and 285 SCF/hp hr were calculated for 4-stroke and 2-stroke engines, respectively. Combining these relationships with the above concentration figures, the "brake specific particulate" estimate for small 4-stroke engines is 0.44 g/hp hr, and that for small 2-stroke engines is 7.1 g/hp hr. Given that these estimates are based only on the 5 test engines, it is assumed implicitly that the 4-stroke engines in question do not consume large quantities of lubricating oil and that the fuel: oil ratio of 16:1 is typical of small air-cooled 2-stroke engines.

All the material in this section thus far has dealt with exhaust emissions, but evaporative losses remain to be computed. These losses will not be included with exhaust hydrocarbon emission factors, but they will be included as a separate number in the impact calculations. Using the loss factor of 2.0 g HC/(gallon tank volume day) which was developed in section III. D., along with the fuel tank volumes shown in Table 18, diurnal losses were calculated and also appear in Table 18. The approximate average molecular weight of the hydrocarbons evaporated from standard emissions test fuel with an Rvp of 9.0 is about 58 g/g mole(8), which means that the average molecule evaporated is somewhere near butane in structure.

TABLE 18. SMALL ENGINE EVAPORATIVE EMISSION ESTIMATES

Engine	Standard Tank Volume, gal.	Evaporative Hydrocarbon Emissions, g/day
B & S 92908	0.25	0.5
B & S 100202	0.75	1.5
Kohler K482	*3.50	7.0
Tecum. AH520	*0.25	0.5
Wisc. S-12D	2.75	5.5

* No standard tank available - volume assumed.

Due to the predominance of engines similar to the Briggs & Stratton 92908 in the lawn and garden category, all these engines will be assumed to have 1-quart tanks for estimates of factors and impact. The remaining engines will be assumed to have 1 gallon tank capacity for each 6 rated horsepower, an average figure for a large number of small engines used in light-duty applications. Evaporative emissions from small lawn and garden engines are seasonal, and they should occur over the same season as engine usage. Fuel left in the tank will change composition in a matter of days to the point where significant evaporation no longer occurs, so it should make little difference whether or not fuel is left in the tank during the off-season. Evaporative emissions from the small engines used in other than lawn and garden applications will likewise be assumed to be seasonal.

Emissions of sulfur oxides (SO_x) have been calculated using the method outlined in section III. D. and a calculated fuel consumption for each category of small engines. These fuel consumption figures were computed using data from the 13-mode tests on the five small engines, and they are assumed typical of the population for purposes of this report.

Emission factors for small engines which are based on all the foregoing analysis, data, and assumptions are given in Table 19. Most of the major variations between engine types have already been discussed in section IV, so it remains only to note the differences between the two categories of 4-stroke engines. These differences are primarily due to rather heavy weighting of the miscellaneous group toward the Briggs & Stratton 100202 and Wisconsin S-12D engines on a power basis, whereas the lawn and garden group is weighted mostly toward the Briggs & Stratton 92908 engine. Since so few engines were tested, the degree to which these estimates represent the real population in the field is not known.

B. Estimation of National Impact

In addition to the emission data already developed, estimation of national impact requires data on the population of engines in service and their breakdown according to size and type. The best current sources for this type of information are the Outdoor Power Equipment Institute(12) and the U.S. Department of Commerce.(15, 16, 17) The latter source was used along with an assumed engine life of five years to arrive at population estimates used in SAE paper 720198(2), and these estimates are shown in Table 20. The Industrial Reports referenced in SAE paper 720198 were for 1968 and earlier, so the populations estimated in Table 20 can probably be assumed to apply to 1968.

Information on sales and populations from OPEI press releases(12) is summarized in Table 21, indicating fairly stable sales for walking mowers and motor tillers. Sales of garden tractors (assumed to be larger than lawn tractors) and snow throwers appear to be increasing somewhat more rapidly. Finally, a more detailed analysis of small engine production (up to 15hp or 26 in^3 displacement) for the years 1966 through 1970 is given in Table 22.(13) Although the coverage of each set of statistics differs somewhat from the others, it appears that there is no substantial

TABLE 19. EMISSION FACTORS FOR SMALL UTILITY ENGINES

Pollutant	Engine Application/Type	Brake Specific Emissions, g/hp hr
Hydrocarbons (Exhaust Only)	Lawn & Garden/4-stroke	23.2
	Lawn & Garden/2-stroke	214.
	Miscellaneous/4-stroke	15.2
CO	Lawn & Garden/4-stroke	279.
	Lawn & Garden/2-stroke	486.
	Miscellaneous/4-stroke	250.
NO_x as NO_2	Lawn & Garden/4-stroke	3.17
	Lawn & Garden/2-stroke	1.58
	Miscellaneous/4-stroke	4.97
RCHO as HCHO	Lawn & Garden/4-stroke	0.49
	Lawn & Garden/2-stroke	2.04
	Miscellaneous/4-stroke	0.47
Particulate	Lawn & Garden/4-stroke	0.44
	Lawn & Garden/2-stroke	7.1
	Miscellaneous/4-stroke	0.44
*SO_x as SO_2	Lawn & Garden/4-stroke	0.37
	Lawn & Garden/2-stroke	0.54
	Miscellaneous/4-stroke	0.39

* Not measured - calculated on basis of 0.043% fuel sulfur content by weight (10).

TABLE 20. PREVIOUS ESTIMATES OF NATIONWIDE SMALL ENGINE POPULATIONS (1968)(2)

Engine Type	Average Rated hp		Engines in Service
Lawn and Garden, 4-stroke	3.43		36,200,000
Lawn and Garden, 2-stroke	3.43		2,500,000
Miscellaneous, 4-stroke	3.86		5,550,000
		Total	44,250,000

TABLE 21. OUTDOOR EQUIPMENT SALES AND POPULATION ESTIMATES(12)

Type of Equipment	Sales or Population for Sales Year ending in Calendar Year (in Millions)						
	*1973	1972	1971	1970	1969	1968	1967
Walking mowers	5.45	5.2	4.7	4.7	4.7	4.56	4.9
Lawn tractors and riding mowers	0.74	0.68	0.875	0.95	1.0	0.93	0.25
Garden tractors	0.265	0.25	**	**	**	**	**
Total lawn & garden	6.455	6.13	5.575	5.65	5.7	5.49	5.15
Estimated total in use	-----	43.	38.	37.	36.	-----	-----
Motor tillers	0.43	0.43	0.365	0.365	0.375	0.375	0.350
Snow throwers	0.33	0.315	0.265	0.245	0.265	0.255	0.185

* predictions

** included with lawn tractors and riding mowers

TABLE 22. BREAKDOWN OF 1966-1970 SMALL ENGINE PRODUCTION BY APPLICATION(13)

Application	Number Produced x 10^{-6}	Percent of Total
Riding mower	2.84	7.1
Walking mower	23.67	59.4
Garden tractor	1.19	3.0
Motor tiller	1.70	4.3
Snow thrower	1.18	3.0
Other lawn & garden	1.31	3.3
Total lawn & garden	31.89	80.0
Recreation	1.10	2.8
Industrial	2.65	6.6
Agriculture	0.97	2.4
Miscellaneous	3.27	8.2
Total	39.88	100.0

disagreement. If it is assumed that the technique resulting in Table 20 is accurate enough for the purposes of this report and that a 15% increase in engine population has occurred since the end of 1968, then estimates of the current population can be calculated. The results of these calculations are given in Table 23, and they will be assumed to apply for calculation of national emissions impact.

TABLE 23. ESTIMATES OF CURRENT SMALL ENGINE POPULATIONS (12/31/72)

Engine Type		Engines in Service
Lawn & Garden, 4-stroke		41,600,000
Lawn & Garden, 2-stroke		2,880,000
Miscellaneous, 4-stroke		6,380,000
	Total	50,900,000

The last few years have seen an increase in the number of garden tractor and riding lawn mower sales, both of which would tend to increase the average power of engines sold. There has been a corresponding increase, however, in the number of snow throwers and other applications of smaller engines, which would tend to decrease the average power of engines sold. The net effect of these changes on average power is probably negligible, so the power figures given in Table 20 will be adopted for use in impact calculations.

Accurate information on annual usage of small engines is not available in any of the references uncovered during the course of this contract. The effort required to obtain such data would be very great, and it remains to be seen if such an effort is justified solely on the basis of increased accuracy in estimating emissions from small engines. The SAE estimate of 50 hours operation per year as an overall average in this small engine category seems reasonable, and no data are available which indicate otherwise. In order to check this estimate for a given application, several reasonable smaller assumptions could be made and another result calculated as shown in the example below for lawnmowers.

Assumptions:
1. each residential lawn covers 10,000 ft^2
2. to account for commercial usage (plants, schools, etc.) and sharing among families, each mower cuts 2 lawn areas
3. each mower cuts a 15-inch swath after correcting for overlap, corners, etc.
4. mower speed is 2 ft/sec
5. grass growing season is 180 days
6. cutting interval during season is 10 days

$$\text{annual usage} = \text{area cut} \times \text{cuttings per year} \times \frac{1}{\text{area cut/unit time}}$$

$$= 10{,}000\ \text{ft}^2 \times 2 \times \frac{180\ \text{days}}{10\ \text{days}} \times \frac{1}{15\ \text{in}(2\ \text{ft/sec})} \times \frac{1\ \text{hr}}{3600\ \text{sec}} \times \frac{12\ \text{in}}{1\ \text{ft}}$$

$$= 40\ \text{hours}$$

Another way of performing such a set of calculations might be to find the number of single-family dwelling units, schools, parks, churches, etc., and assign an arbitrary area to each one. One could then assume a value for grass-cutting speed (area per unit time) and arrive at a total usage for all lawnmowers. No matter which procedure is employed, basic assumptions must be made in lieu of extensive research. Considering that engines used in some applications (such as snow throwers and edgers) are probably used less than lawnmowers, and that engines in other applications (such as recreational, industrial, and agricultural) are probably used more than lawnmowers, the overall estimate of 50 hours usage per year still seems logical, and will be used for calculations.

Based on all the foregoing analysis, national emissions impact of small engines has been calculated and is presented in Table 24 along with emissions per engine in service. The contribution of small engines to the nationwide air pollution problem can perhaps better be assessed by comparing small engine emissions with EPA National Inventory Data(18), as is shown in Table 25. It should be noted that the EPA data are for 1970, but that the small engine emissions are assumed applicable to the end of 1972. The growth rate in small utility engine sales is currently around 6% per year, and no major change in that rate seems likely. Some fluctuations occur from year to year, of course, but the domination of the market by sales for lawn and garden applications seems to assure a measure of stability.

Although no data are currently available on the geographical distribution of small engines in service, it seems reasonable that the density of lawn and garden equipment is proportional to the density of suburban and rural single-family dwelling units. This statistic may be available from the Bureau of the Census, or as an alternative, manufacturers probably have a good idea of the regional distribution of their sales. The miscellaneous category is probably distributed more in proportion with the population, disregarding urban/suburban or rural residency.

It has already been noted that small engine usage is highly seasonal, occurring almost entirely during the "summer half" of the year. The length of the season for lawn work varies from perhaps 5 months in the northern states to 9 months or more in the southern states, indicating that small engine usage may be considerably higher in the South than

TABLE 24. NATIONAL EMISSIONS IMPACT ESTIMATES FOR SMALL ENGINES

		Mass Emissions		Total for Pollutant, ton/yr
Pollutant	Engine Application/Type	g/unit yr	ton/yr	
Hydrocarbons (Exhaust)	Lawn & Garden/4-stroke	1,590	73,000	
	Lawn & Garden/2-stroke	14,700	46,600	
	Miscellaneous/4-stroke	1,170	8,250	128,000
Hydrocarbons (Evaporative)	Lawn & Garden/4-stroke	113	5,170	
	Lawn & Garden/2-stroke	113	358	
	Miscellaneous/4-stroke	290	2,040	7,560
Hydrocarbons (Total)	Lawn & Garden/4-stroke	1,700	78,100	
	Lawn & Garden/2-stroke	14,800	47,000	
	Miscellaneous/4-stroke	1,460	10,300	135,000
CO	Lawn & Garden/4-stroke	19,100	878,000	
	Lawn & Garden/2-stroke	33,400	106,000	
	Miscellaneous/4-stroke	19,300	136,000	1,119,000
NO_x as NO_2	Lawn & Garden/4-stroke	217	9,970	
	Lawn & Garden/2-stroke	108	344	
	Miscellaneous/4-stroke	384	2,700	13,000
RCHO as HCHO	Lawn & Garden/4-stroke	34	1,540	
	Lawn & Garden/2-stroke	140	444	
	Miscellaneous/4-stroke	36	255	2,240
Particulate	Lawn & Garden/4-stroke	31	1,400	
	Lawn & Garden/2-stroke	470	1,500	
	Miscellaneous/4-stroke	34	240	3,200
SO_x as SO_2	Lawn & Garden/4-stroke	26	1,200	
	Lawn & Garden/2-stroke	38	120	
	Miscellaneous/4-stroke	30	210	1,500

TABLE 25. COMPARISON OF SMALL ENGINE NATIONAL IMPACT ESTIMATES WITH EPA NATIONWIDE AIR POLLUTANT INVENTORY DATA

	1970 EPA Inventory Data, 10^6 tons/yr(18)		Small Engine Estimates as % of	
Contaminant	All Sources	Mobile Sources	All Sources	Mobile Sources
HC	34.7	19.5	0.389	0.692
CO	147.	111.	0.761	1.01
NO_x	22.7	11.7	0.0573	0.111
SO_x	33.9	1.0	0.0044	0.15
Particulates	25.4	0.7	0.013	0.46

in the North. This trend should hold almost as well for engines used in agriculture and industry as for those used in lawn and garden work, since they are virtually all operated outdoors.

To summarize variations in emissions based on season, region, and urban/rural considerations, Table 26 has been prepared to show small engine emissions classified by these three factors. The table is based on 1970 data(19), assuming: (1) that the number of small engines in each region is proportional to its population; (2) that the numbers of lawn and garden engines in urban/suburban and rural areas are proportional to the suburban and rural populations, respectively; and (3) that small engines are used 5 months in the northern region, 7 months in the central region, and 9 months in the southern region. The northern region is roughly between 49° and 43° N. latitude, the central region between 43° and 37°, and the south region is between 37° and 31°. States straddling the established

TABLE 26. SUMMARY OF SEASONAL, REGIONAL, AND URBAN-RURAL VARIATIONS IN SMALL ENGINE EMISSIONS

	Percentage of Annual Nationwide Emissions by Season								
	Urban/Suburban Areas				Rural Areas				
Region	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Subtotals
Northern	0.0	0.75	2.27	0.75	0.0	0.50	1.50	0.50	6.27
Central	0.0	9.18	13.77	9.18	0.0	5.62	8.44	5.62	51.81
Southern	0.0	8.61	8.61	8.61	0.0	5.37	5.37	5.37	41.94
Subtotals	0.0	18.54	24.65	18.54	0.0	11.49	15.31	11.49	
Totals	61.73				38.29				100.02

borderlines were placed in the regions containing the majorities of their populations. This seasonal/regional analysis is really simplistic, but it does yield some valuable results. It appears, for instance, that a substantial majority of small engine emissions occur in urban/suburban areas rather than rural areas. These emissions would not be directly additional to those from automobiles and other sources, however, because they are released mainly during non-working hours and weekends. It is also interesting to note in Table 26 that around 40% of small engine emissions appear to occur in the midsummer months, and that few emissions occur in midwinter. Spring appears to account for about 30% of small engine emissions, and fall the remaining 30%. The regional breakdown estimates that the central region probably receives about 52% of small engine emissions, the northern region about 6%, and the southern region about 42%. These percentages are similar to those for population (55.6%, 9.4%, and 35.0% for central, northern, and southern regions, respectively), but are weighted a little more heavily toward the southern region due to the more favorable climate for outdoor work and the longer grass-growing season.

VI. SUMMARY

This report is the end product of a study on exhaust emissions from small air-cooled, gasoline-fueled utility engines, and it is Part 4 of a planned seven-part final report on "Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines," Contract EHS 70-108. It includes test data, documentation, and discussion on detailed emissions characterization of five engines (one 2-stroke and four 4-stroke), as well as estimated emission factors and national emissions impact. As a part of the final report on the characterization phase of EHS 70-108, this report does not include information on aircraft turbine emissions, outboard motor crankcase drainage, or locomotive emissions control technology. As required by the contract, these three latter areas have been or will be reported on separately.

The emission measurements on the five small engines were conducted in the Emissions Research Laboratory and the Engine Laboratory of the Department of Automotive Research by the staff of the Emissions Research Laboratory. Data were acquired during steady-state operation according to both the "EMA 13-mode" (modified version) and "SAE 9-mode" procedures, and some information was developed during transient operation, also.

The exhaust products measured included total hydrocarbons by FIA; CO, CO_2, NO, and hydrocarbons by NDIR; O_2 by electrochemical analysis; light hydrocarbons by gas chromatograph; aldehydes by wet chemistry; particulates by gravimetric analysis; and smoke (for the 2-stroke engine only) by the PHS light extinction smokemeter. Fuel evaporative losses and SO_x emissions were calculated rather than being measured, and emission factors and national impact were computed for hydrocarbons (total), CO, NO_x, RCHO (aldehydes), particulate, and SO_x.

Expressing small engine emissions as percentages of 1970 national totals from all sources, small engines appear to account for approximately 0.4% of hydrocarbons, 0.8% of CO, 0.06% of NO_x, 0.004% of SO_x, and 0.01% of particulates. As percentages of 1970 mobile source emissions, small engines are estimated to be responsible for about 0.7% of hydrocarbons, 1.0% of CO, 0.1% of NO_x, 0.2% of SO_x, and 0.5% of particulates. The impact of small engine emissions has been estimated for three regions based on population and climatic considerations, with the result that about 6% of small engine emissions appear to occur in the northern region, 52% in the central region, and 42% in the southern region.

If it is decided that small engine emissions may become significant in the national picture, it seems obvious that further research would be required to establish a more reliable baseline. It would be necessary first to test additional engines of various sizes and types, preferably a statistical sampling of in-service units or long-term tests on new units. Other very weak points in the current status of information are number of engines in use, operating patterns, and annual usage. These areas would probably best be handled on a survey basis, but are quite necessary to making accurate assessments. The possible future importance of the small engine category can be appreciated by considering that small engines rank second only to highway vehicles in number of engines currently in use, although of course they are much smaller in size. This fact combined with rapidly growing sales and populations of these engines makes the potential future impact of small engine emissions much greater than it is at present.

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APPENDIX A

Emissions Data From 13-Mode Tests

Mode	Engine Speed, rpm	Observed Power, hp	Fuel, lbm/hr	Air, lb_m/hr	Temperature, °F		Wet Concentrations					
					Intake	Exhaust	FIA HC, ppmC	NDIR HC, $ppmC_6$	NDIR CO, %	NDIR CO_2, %	NDIR NO, ppm	Polar. O_2, %
1	1760	0.04	0.52	6.2	85	240	14,500	898	7.08	7.01	54	2.6
2	2600	0.07	0.86	9.6	86	285	9,600	610	7.25	7.74	81	0.8
3	2600	0.60	0.94	10.8	86	380	8,200	583	6.70	8.41	95	0.7
4	2600	1.26	1.08	12.8	86	430	8,500	580	6.57	8.27	109	1.2
5	2600	1.86	1.32	14.8	86	450	9,100	702	8.34	7.07	81	1.5
6	2600	3.06	1.73	18.2	86	540	9,000	662	9.06	6.73	73	0.9
7	1710	0.04	0.58	6.2	86	255	17,000	—	7.69	6.97	47	1.3
8	3600	2.95	1.83	25.0	86	750	4,200	324	1.97	11.8	1230	0.3
9	3600	2.16	2.21	22.7	86	670	8,700	583	9.05	6.87	94	0.3
10	3600	1.41	1.71	20.4	85	630	7,000	528	6.00	8.96	207	0.8
11	3600	0.70	1.46	17.6	84	580	6,800	446	6.21	9.62	170	0.8
12	3600	0.09	1.25	16.5	84	555	5,300	349	3.66	10.6	238	0.9
13	1620	0.04	0.53	6.0	84	420	13,400	876	6.95	6.80	54	1.6

Engine BRIGGS & STRATTON 92908 Date 4/28/71 Wet Bulb Temperature 74 F

Procedure 13-MODE Barometer, in Hg 28.86 Dry Bulb Temperature 83 F

Run 2

					Temperature, °F		Wet Concentrations					
Mode	Engine Speed, rpm	Observed Power, hp	Fuel, lbm/hr	Air, lb_m/hr	Intake	Exhaust	FIA HC, ppmC	NDIR HC, $ppmC_6$	NDIR CO, %	NDIR CO_2, %	NDIR NO, ppm	Polar. O_2, %
1	1650	0.03	0.43	5.7	83	210	13,800	743	3.63	6.37	35	2.8
2	2600	0.05	0.75	9.1	83	330	9,800	477	4.07	7.37	55	0.9
3	2600	0.63	0.84	10.8	84	385	5,600	359	2.99	8.56	91	0.5
4	2600	1.30	0.88	11.9	84	410	5,100	351	2.78	8.57	106	1.1
5	2600	1.95	1.88	14.2	84	470	7,200	325	5.26	6.99	76	1.2
6	2600	2.68	1.63	18.2	84	550	15,400	423	5.01	5.21	35	1.5
7	1760	0.07	0.52	6.2	84	430	13,600	—	7.00	7.16	54	2.3
8	3600	3.48	1.92	24.4	85	680	5,500	411	4.00	8.97	377	0.8
9	3600	2.33	2.19	22.7	85	660	9,300	593	8.92	6.31	88	0.7
10	3600	1.61	1.62	19.3	86	620	5,900	483	5.66	8.34	159	0.7
11	3600	0.83	1.30	17.0	86	600	4,500	371	3.42	9.88	225	0.7
12	3600	0.10	1.06	15.3	86	580	4,100	274	0.92	11.3	288	0.9
13	1730	0.05	0.54	6.2	87	460	16,000	—	6.80	5.90	55	2.3

Engine BRIGGS & STRATTON 92908 Date 4/29/71 Wet Bulb Temperature 73 F

Procedure 13-MODE Barometer, in Hg 28.84 Dry Bulb Temperature 83 F

Run 3

Mode	Engine Speed, rpm	Observed Power, hp	Fuel, lbm/hr	Air, lb_m/hr	Temperature, °F		Wet Concentrations					
					Intake	Exhaust	FIA HC, ppmC	NDIR HC, $ppmC_6$	NDIR CO, %	NDIR CO_2, %	NDIR NO, ppm	Polar. O_2, %
1	1690	0.04	0.46	5.2	78	210	20,000	—	7.02	6.87	47	2.4
2	2600	0.05	0.81	9.2	78	295	10,100	765	6.84	8.40	88	0.6
3	2600	0.66	0.84	10.4	78	365	7,500	642	4.66	10.2	129	0.4
4	2600	1.31	0.96	11.8	78	420	8,200	707	5.12	9.73	172	0.9
5	2600	1.97	1.14	13.6	79	470	9,100	738	5.99	9.13	178	0.9
6	2600	2.91	1.90	17.9	79	560	17,200	—	10.3	5.18	46	1.0
7	1780	0.03	0.55	5.8	79	285	19,400	—	7.86	6.81	54	1.3
8	3600	3.27	1.95	23.7	80	695	8,000	568	6.13	8.95	279	0.4
9	3600	2.41	1.69	21.1	81	680	8,500	495	3.64	11.0	624	0.4
10	3600	1.60	1.65	19.1	84	665	8,600	457	3.11	11.2	626	0.5
11	3600	0.79	1.34	17.0	85	620	9,100	503	2.87	11.2	418	0.5
12	3600	0.09	1.13	16.2	86	600	9,400	272	0.59	12.5	487	0.5
13	1720	0.04	0.57	6.1	86	490	17,200	—	8.01	7.02	53	1.3

Engine BRIGGS & STRATTON 92908 Date 4/30/71 Wet Bulb Temperature 68 F

Procedure 13-MODE Barometer, in Hg 29.02 Dry Bulb Temperature 79 F

Run 4

							Wet Concentrations					
Mode	Engine Speed, rpm	Observed Power, hp	Fuel, lbm/hr	Air, lbm/hr	Temperature, °F Intake	Temperature, °F Exhaust	FIA HC, ppmC	NDIR HC, ppmC6	NDIR CO, %	NDIR CO2, %	NDIR NO, ppm	Polar. O2, %
1	1790	0.04	0.45	5.7	90	210	9,300	470	5.26	9.46	69	0.8
2	2200	0.05	0.59	7.9	90	300	6,900	368	0.54	11.3	155	0.9
3	2200	0.59	0.64	9.1	91	340	4,700	268	0.19	11.1	345	1.4
4	2200	1.06	0.67	10.8	92	400	3,850	246	0.12	10.8	514	2.2
5	2200	2.00	0.73	12.5	92	430	3,550	280	0.10	10.0	707	3.1
6	2200	2.56	1.37	14.2	92	450	9,700	604	8.80	5.53	68	1.2
7	1770	0.04	0.44	5.7	92	230	8,900	502	3.64	8.83	76	1.1
8	3100	3.13	1.73	20.4	94	610	9,000	544	7.42	6.41	124	0.9
9	3100	2.45	1.20	18.1	93	620	3,700	231	0.39	11.3	1700	1.2
10	3100	1.57	1.05	17.0	93	590	3,200	181	0.14	10.7	684	2.3
11	3100	0.79	0.98	15.9	94	570	3,000	159	0.14	10.6	616	2.2
12	3100	0.08	0.79	15.3	94	530	7,850	468	0.17	8.95	115	5.8
13	1830	0.04	0.47	6.2	94	260	8,200	414	3.27	8.95	76	1.2

Engine BRIGGS & STRATTON 92908 Date 5/3/71 Wet Bulb Temperature 64 F

Procedure 13-MODE Barometer, in Hg 29.06 Dry Bulb Temperature 90 F

Run 5

Mode	Engine Speed, rpm	Observed Power, hp	Fuel, lbm/hr	Air, lbm/hr	Temperature, °F		Wet Concentrations					
					Intake	Exhaust	FIA HC, ppmC	NDIR HC, ppmC6	NDIR CO, %	NDIR CO_2, %	NDIR NO, ppm	Polar. O_2, %
1	1700	0.05	0.43	5.3	78	250	14,600	968	7.47	6.00	41	3.7
2	2600	0.15	0.69	8.3	78	280	6,700	508	5.43	9.26	95	0.6
3	2600	0.70	0.90	11.8	76	400	4,700	363	2.95	11.2	327	0.3
4	2600	1.30	1.14	15.3	76	500	5,000	432	3.19	10.1	550	1.0
5	2600	1.90	1.50	20.0	77	600	4,400	558	5.32	8.05	360	2.4
6	2600	2.50	1.61	23.6	77	680	1,800	237	4.60	8.10	587	3.4
7	1600	0.05	0.44	5.3	77	280	15,500	932	7.31	5.87	47	3.6
8	3600	2.95	1.90	31.3	77	820	1,600	161	1.05	10.5	1820	3.0
9	3600	2.15	1.60	24.8	78	730	1,700	160	1.16	10.8	1400	2.0
10	3600	1.50	1.37	20.7	77	650	1,600	128	0.70	11.5	1120	1.2
11	3600	0.85	1.12	17.1	78	560	1,450	108	0.31	11.7	693	1.2
12	3600	0.25	0.87	13.0	78	490	1,550	97	0.31	11.9	310	0.8
13	1675	0.05	0.42	5.3	78	250	14,200	67	6.72	6.04	41	3.6

Engine BRIGGS & STRATTON 100202 Date 4/5/71 Wet Bulb Temperature 53 F

Procedure 13-MODE Barometer, in Hg 29.38 Dry Bulb Temperature 73 F

Run 1

Mode	Engine Speed, rpm	Observed Power, hp	Fuel, lbm/hr	Air, lb_m/hr	Temperature, °F		Wet Concentrations					
					Intake	Exhaust	FIA HC, ppmC	NDIR HC, ppmC_6	NDIR CO, %	NDIR CO_2, %	NDIR NO, ppm	Polar. O_2, %
1	1730	0.05	0.46	5.4	70	220	12,800	956	7.18	6.49	41	2.6
2	2600	0.15	0.64	7.8	70	280	5,900	481	5.32	9.01	88	0.6
3	2600	0.75	0.78	10.2	70	360	4,300	361	3.22	10.4	210	0.3
4	2600	1.40	1.18	14.4	70	490	3,500	306	2.97	10.7	750	0.2
5	2600	2.05	1.68	19.8	72	600	4,000	358	5.75	8.74	402	0.2
6	2600	2.65	1.81	22.8	72	680	2,500	225	4.47	9.69	763	0.3
7	1700	0.10	0.45	5.4	72	270	12,000	843	7.12	6.36	27	2.7
8	3600	3.00	2.03	30.0	72	820	1,400	128	0.39	11.9	2550	0.9
9	3600	2.30	1.70	24.5	73	730	1,650	144	1.03	11.8	1820	0.5
10	3600	1.60	1.40	21.0	73	650	1,500	127	0.49	11.9	1340	0.9
11	3600	0.90	1.12	17.4	74	560	1,150	95	0.27	11.7	676	1.4
12	3600	0.25	0.90	13.8	74	490	1,000	91	0.31	11.7	266	1.2
13	1700	0.05	0.42	5.4	74	230	9,700	744	6.62	6.31	27	3.5

Engine BRIGGS & STRATTON 100202 Date 4/6/71 Wet Bulb Temperature 52 F

Procedure 13-MODE Barometer, in Hg 29.56 Dry Bulb Temperature 69 F

Run 2

Mode	Engine Speed, rpm	Observed Power, hp	Fuel, lbm/hr	Air, lbm/hr	Temperature, °F		Wet Concentrations					
					Intake	Exhaust	FIA HC, ppmC	NDIR HC, ppmC6	NDIR CO, %	NDIR CO2, %	NDIR NO, ppm	Polar. O2, %
1	1700	0.05	0.44	5.4	70	220	15,800	981	7.08	5.95	22	3.5
2	2200	0.10	0.55	6.6	74	220	9,900	555	6.36	7.35	33	1.8
3	2200	0.55	0.66	8.9	74	290	5,500	345	3.38	9.71	182	1.2
4	2200	1.05	0.93	12.5	74	390	5,100	326	3.16	9.91	581	1.1
5	2200	1.55	1.20	15.5	75	420	5,600	315	4.08	9.38	579	1.0
6	2200	2.05	1.48	19.7	74	580	4,500	202	3.60	9.69	1100	1.1
7	1750	0.05	0.44	5.4	74	240	18,600	981	7.23	5.88	22	4.0
8	3100	2.95	1.98	28.6	74	780	2,750	63	0.87	11.6	2460	0.6
9	3100	2.35	1.96	23.3	75	650	4,200	174	5.96	8.47	394	0.5
10	3100	1.65	1.32	17.9	75	560	4,200	602	2.35	10.5	1010	0.6
11	3100	0.90	0.91	13.7	76	470	2,600	320	0.34	11.6	825	1.0
12	3100	0.20	0.74	9.5	75	340	5,700	426	4.27	9.54	89	0.9
13	1760	0.05	0.46	5.4	75	200	18,800	1020	7.62	5.86	22	3.5

Engine BRIGGS & STRATTON 100202 Date 4/7/71 Wet Bulb Temperature 51 F

Procedure 13-MODE Barometer, in Hg 29.46 Dry Bulb Temperature 73 F

Run 3

Mode	Engine Speed, rpm	Observed Power, hp	Fuel, lbm/hr	Air, lb_m/hr	Temperature, °F		Wet Concentrations					
					Intake	Exhaust	FIA HC, ppmC	NDIR HC, ppmC_6	NDIR CO, %	NDIR CO_2, %	NDIR NO, ppm	Polar. O_2, %
1	1120	0.0	1.57	10.5	74	275	36,000	—	5.93	5.81	62	5.6
2	2300	0.1	2.63	24.0	74	315	8,400	417	5.68	8.02	61	2.4
3	2300	2.8	4.15	36.3	74	405	8,100	405	6.98	7.46	75	1.6
4	2300	5.6	5.25	51.5	74	510	6,900	385	6.65	8.02	158	1.5
5	2300	9.3	5.44	73.1	75	655	4,200	214	2.42	10.9	1340	1.3
6	2300	11.3	6.78	93.6	76	760	3,300	184	2.42	10.9	1670	1.3
7	1150	0.0	1.45	11.1	72	290	43,800	—	5.97	5.16	77	6.5
8	3600	15.1	12.2	135.	78	885	4,800	241	5.37	9.27	510	0.5
9	3600	11.2	10.3	108.	78	810	5,400	253	6.15	8.62	339	0.6
10	3600	7.6	7.68	84.8	80	740	4,200	191	4.37	9.71	396	0.8
11	3600	3.9	6.64	67.3	78	620	5,100	220	5.90	8.48	151	1.0
12	3600	0.3	5.60	52.0	77	510	7,200	264	7.21	7.15	75	1.5
13	1120	0.0	1.44	10.5	76	245	35,400	—	5.94	5.69	77	5.8

Engine KOHLER K482 Date 3/24/71 Wet Bulb Temperature 56 F

Procedure 13-MODE Barometer, in Hg 29.06 Dry Bulb Temperature 69 F

Run 2

Mode	Engine Speed, rpm	Observed Power, hp	Fuel, lbm/hr	Air, lb_m/hr	Temperature, °F Intake	Temperature, °F Exhaust	Wet Concentrations FIA HC, ppmC	NDIR HC, ppmC_6	NDIR CO, %	NDIR CO_2, %	NDIR NO, ppm	Polar. O_2, %
1	1110	0.0	2.11	11.9	82	330	61,800	4770	6.41	4.30	135	7.9
2	1800	0.1	2.43	17.6	82	270	28,800	1900	6.90	6.50	61	3.5
3	1800	2.3	3.08	26.2	82	340	10,200	780	7.07	7.00	68	2.5
4	1800	4.5	4.20	38.7	84	440	8,700	690	6.76	7.55	120	1.8
5	1800	6.7	5.95	56.9	95	540	9,000	700	8.70	6.50	88	1.4
6	1800	8.9	9.93	108.0	85	645	19,200	940	10.84	5.30	53	1.1
7	1115	0.0	1.94	11.9	83	285	78,700	4920	6.25	3.60	144	8.2
8	3000	13.9	9.63	119.0	88	830	4,200	520	4.60	9.80	690	0.6
9	3000	10.5	7.30	91.0	88	770	4,200	450	4.20	9.90	630	0.8
10	3000	7.0	6.14	71.0	88	660	4,200	380	4.50	9.60	310	1.4
11	3000	3.6	5.38	52.9	89	545	5,700	420	6.60	7.80	95	1.4
12	3000	0.1	4.31	38.1	89	455	12,600	650	7.40	6.70	61	2.1
13	1140	0.0	1.55	12.5	90	265	77,800	4920	6.00	3.75	140	8.2

Engine KOHLER K482 Date 3/25/71 Wet Bulb Temperature 68 F

Procedure 13-MODE Barometer, in Hg 28.90 Dry Bulb Temperature 79 F

Run 3

Mode	Engine Speed, rpm	Observed Power, hp	Fuel, lbm/hr	Air, lb_m/hr	Temperature, °F		Wet Concentrations					
					Intake	Exhaust	FIA HC, ppmC	NDIR HC, ppmC$_6$	NDIR CO, %	NDIR CO$_2$, %	NDIR NO, ppm	Polar. O$_2$, %
1	1100	0.0	1.83		76	440	57,600	2540	3.87	3.76	110	8.1
2	2300	0.1	2.88		75	430	11,400	412	4.12	7.28	77	2.5
3	2300	3.1	4.10		75	510	6,900	304	3.96	7.60	105	1.9
4	2300	6.0	5.66		76	610	5,700	257	3.52	8.26	200	1.7
5	2300	9.0	8.13		77	720	6,000	287	5.19	7.14	140	1.8
6	2300	11.9	10.7		73	790	6,000	309	6.58	6.05	90	2.0
7	1140	0.0	1.93		78	450	60,600	3860	4.00	4.00	102	8.6
8	3600	14.6	14.5		78	920	5,700	287	5.25	7.06	133	0.7
9	3600	11.0	10.8		90	900	5,100	178	3.94	8.15	228	0.9
10	3600	7.4	8.37		92	830	4,500	133	2.78	8.40	245	0.9
11	3600	3.8	6.73		79	730	4,800	137	3.30	8.04	127	1.2
12	3600	0.2	5.39		79	640	5,400	130	3.32	7.42	92	1.9
13	1050	0.0	1.82		78	360	71,300	4270	4.12	3.57	124	9.0

Engine KOHLER K482 Date 3/26/71 Wet Bulb Temperature 56 F

Procedure 13-MODE Barometer, in Hg 29.16 Dry Bulb Temperature 68 F

Run 4

							Wet Concentrations					
	Engine Speed, rpm	Observed Power, hp	Fuel, lbm/hr	Air, lb_m/hr	Temperature, °F		FIA HC, ppmC	NDIR HC, $ppmC_6$	NDIR CO, %	NDIR CO_2, %	NDIR NO, ppm	Polar. O_2, %
Mode					Intake	Exhaust						
1	3300	0.19	0.69	7.6	80	320	49,200	4750	3.68	7.54	56	5.4
2	3500	0.21	0.41	8.1	80	350	40,800	3960	3.49	7.80	63	4.7
3	3500	0.50	1.04	11.0	80	405	37,200	3750	5.11	7.43	55	3.8
4	3500	0.83	1.41	13.9	80	450	40,800	4150	5.50	6.97	55	4.0
5	3500	1.14	1.75	17.1	80	500	45,600	4810	5.77	6.30	69	4.6
6	3500	1.60	2.54	23.2	81	560	54,400	6050	4.97	6.00	92	5.6
7	3300	0.20	0.67	7.6	81	440	40,800	3900	3.31	7.56	42	5.5
8	4500	1.68	2.52	24.4	81	590	49,200	4890	6.59	5.91	76	4.9
9	4500	1.23	1.95	19.7	82	580	42,000	4320	6.02	6.50	83	4.4
10	4500	0.91	1.68	17.4	82	560	40,200	3840	6.02	6.35	83	4.2
11	4500	0.58	1.42	14.5	82	540	42,600	4080	5.64	6.52	83	4.2
12	4500	0.28	1.02	11.3	83	470	39,000	3860	4.70	7.10	69	4.5
13	3350	0.21	0.66	7.6	83	380	44,400	4570	3.45	7.40	70	5.0

Engine TECUMSEH AH520 T1448 Date 4/12/71 Wet Bulb Temperature 63 F

Procedure 13-MODE Barometer, in Hg 29.19 Dry Bulb Temperature 80 F

Run 1

Mode	Engine Speed, rpm	Observed Power, hp	Fuel, lb_m/hr	Air, lb_m/hr	Temperature, °F		Wet Concentrations					
					Intake	Exhaust	FIA HC, ppmC	NDIR HC, $ppmC_6$	NDIR CO, %	NDIR CO_2, %	NDIR NO, ppm	Polar. O_2, %
1	3300	0.20	0.65	7.6	73	290	34,500	3720	2.86	8.81	76	3.8
2	3500	0.22	0.70	8.2	74	295	29,100	3080	2.38	9.37	55	3.4
3	3500	0.47	1.05	11.1	74	345	31,200	3420	4.12	8.30	76	3.4
4	3500	0.76	1.33	13.7	74	405	38,400	4520	4.58	7.33	84	4.0
5	3500	1.03	1.59	16.9	75	450	42,000	5640	4.39	6.97	98	4.9
6	3500	1.42	2.10	22.7	76	495	51,600	7240	3.35	6.67	143	6.4
7	3300	0.20	0.68	7.6	77	350	34,800	4530	3.57	8.18	98	3.6
8	4500	1.58	2.15	24.2	78	540	40,200	4130	3.06	7.91	142	4.8
9	4500	1.17	1.75	18.7	78	525	36,000	3750	3.60	7.33	99	3.8
10	4500	0.86	1.45	16.3	79	515	28,800	3410	4.33	8.29	104	3.4
11	4500	0.55	1.24	14.0	79	475	25,800	2930	4.75	8.25	104	3.1
12	4500	0.27	0.92	11.1	80	450	26,400	3000	3.54	8.84	126	2.9
13	3300	0.20	0.66	7.6	[illegible]	355	32,400	3790	3.56	8.26	62	3.7

Engine TECUMSEH AH520 T1448 Date 4/13/71 Wet Bulb Temperature 65 F

Procedure 13-MODE Barometer, in Hg 29.12 Dry Bulb Temperature 77 F

Run 2

							Wet Concentrations					
Mode	Engine Speed, rpm	Observed Power, hp	Fuel, lbm/hr	Air, lbm/hr	Temperature, °F Intake	Temperature, °F Exhaust	FIA HC, ppmC	NDIR HC, ppmC6	NDIR CO, %	NDIR CO2, %	NDIR NO, ppm	Polar. O2, %
1	1050	0.1	0.56	9.2	76	360	12,000	—	1.04	11.2	76	—
2	2300	0.4	1.96	21.1	76	450	9,000	504	6.42	8.35	88	—
3	2300	1.7	2.27	28.1	77	560	4,800	323	3.86	10.2	187	—
4	2300	3.4	2.63	39.2	79	720	2,100	169	0.38	11.9	1130	—
5	2300	5.0	3.10	51.0	80	810	1,500	111	0.26	11.5	1700	—
6	2300	7.5	4.12	60.3	80	880	1,300	162	1.41	10.4	1960	—
7	1130	0.1	0.60	9.4	78	350	8,400	637	1.78	10.6	67	—
8	3600	9.4	8.75	93.2	81	940	4,800	273	8.87	6.73	188	—
9	3600	7.0	6.72	72.7	82	850	5,400	308	8.70	6.66	132	—
10	3600	4.7	5.57	60.9	82	900	5,100	283	7.80	7.40	155	—
11	3600	2.5	4.08	48.0	82	720	5,100	245	6.29	8.36	133	—
12	3600	0.3	3.43	37.5	82	640	7,500	327	7.80	7.47	99	—
13	800	0.0	0.47	8.2	80	300	16,200	—	0.15	9.12	93	—

Engine WISCONSIN S-12D Date 3/30/71 Wet Bulb Temperature 56 F

Procedure 13-MODE Barometer, in Hg 29.30 Dry Bulb Temperature 78 F

Run 1

Mode	Engine Speed, rpm	Observed Power, hp	Fuel, lbm/hr	Air, lbm/hr	Temperature, °F Intake	Temperature, °F Exhaust	Wet Concentrations FIA HC, ppmC	NDIR HC, ppmC6	NDIR CO, %	NDIR CO2, %	NDIR NO, ppm	Polar. O2, %
1	1150	0.1	0.60	8.6	80	350	7,800	556	2.97	10.8	89	1.1
2	1850	0.1	1.30	14.3	80	330	9,000	481	6.17	8.30	88	1.0
3	1850	1.7	1.89	22.3	80	470	5,400	291	4.37	9.62	215	0.9
4	1850	3.2	2.47	31.5	81	580	4,200	246	3.24	10.1	886	1.4
5	1850	4.8	3.20	42.3	82	690	3,300	181	2.76	9.50	1370	2.7
6	1850	6.5	3.98	53.8	84	760	2,700	160	3.10	9.05	1300	3.2
7	1150	0.0	0.63	8.6	82	340	8,400	503	1.71	11.2	113	1.1
8	3000	9.4	6.92	82.4	86	970	3,900	66	5.64	8.75	573	0.4
9	3000	7.0	5.57	68.7	87	930	3,600	56	4.91	9.40	626	0.4
10	3000	4.7	4.34	53.8	87	840	3,300	56	4.58	9.60	421	0.3
11	3000	2.4	3.12	38.9	86	710	3,900	95	4.21	9.81	250	0.4
12	3000	0.2	2.50	27.5	83	590	7,800	315	5.65	8.50	134	0.6
13	1150	0.1	0.63	8.6	82	320	8,400	710	3.23	10.3	66	1.0

Engine WISCONSIN S-12D Date 3/31/71 Wet Bulb Temperature 66 F

Procedure 13-MODE Barometer, in Hg 29.00 Dry Bulb Temperature 80 F

Run 2

Mode	Engine Speed, rpm	Observed Power, hp	Fuel, lbm/hr	Air, lbm/hr	Temperature, °F		Wet Concentrations					
					Intake	Exhaust	FIA HC, ppmC	NDIR HC, ppmC6	NDIR CO, %	NDIR CO2, %	NDIR NO, ppm	Polar. O2, %
1	1120	0.1	0.60	8.6	82	400	7,500	294	—	10.6	69	1.6
2	2300	0.1	1.63	17.2	82	400	8,500	276	—	8.11	70	1.6
3	2300	2.4	2.50	32.2	82	550	5,400	137	—	8.91	171	1.0
4	2300	3.9	3.19	40.2	83	670	4,200	95	—	10.2	492	1.0
5	2300	5.7	4.28	54.0	84	830	3,200	55	—	10.8	1160	1.6
6	2300	7.2	5.06	59.8	84	870	2,700	72	—	9.71	1150	2.9
7	1150	0.1	0.50	8.6	85	520	9,200	285	—	8.83	55	1.3
8	3600	9.5	8.31	94.2	86	960	4,000	124	—	6.97	141	1.9
9	3600	7.0	7.71	81.6	86	910	4,800	164	—	6.17	92	1.5
10	3600	4.8	7.18	70.7	87	870	6,100	182	—	5.89	70	1.2
11	3600	2.6	5.22	55.2	87	800	6,700	130	—	6.65	85	0.6
12	3600	0.3	4.18	42.0	87	720	10,100	227	—	6.38	71	0.8
13	1150	0.0	0.65	3.6	86	450	13,600	448	—	8.24	63	1.5

Engine WISCONSIN S-12D Date 4/1/71 Wet Bulb Temperature 61 F

Procedure 13-MODE Barometer, in Hg 29.09 Dry Bulb Temperature 79 F

Run 3

APPENDIX B

Emissions Data From 9-Mode Tests and From 30-Mode Test on B & S 92908 Engine

Mode	Engine Speed, rpm	Observed Power, hp	Fuel, lb_m/hr	Air, lb_m/hr	Temperature, °F		Wet Concentrations					
					Intake	Exhaust	FIA HC, ppmC	NDIR HC, ppmC$_6$	NDIR CO, %	NDIR CO$_2$, %	NDIR NO, ppm	Polar. O$_2$, %
1	3600	3.16	1.96	25.7	88	640	5,600	331	3.57	10.6	611	0.8
2	3600	1.58	1.84	20.3	89	630	7,800	475	8.31	7.36	101	1.0
3	3600	0.08	1.14	15.7	90	570	5,300	296	2.63	11.3	239	1.0
4	3600	3.50	2.14	25.7	94	720	6,200	429	6.13	8.95	264	0.9
5	3600	1.70	2.05	20.3	94	640	7,700	554	8.78	6.89	80	0.3
6	3600	0.09	1.28	16.2	93	570	5,800	367	4.46	9.97	151	0.7
7	3600	3.46	1.75	25.7	94	770	4,300	254	0.70	12.3	1560	1.1
8	3600	1.72	1.70	20.3	94	660	7,100	430	5.87	8.97	193	0.7
9	3600	0.08	1.13	16.2	95	575	4,600	249	1.14	12.0	407	0.9
10												
11												
12												
13												

Engine BRIGGS & STRATTON 92908 Date 4/28/71 Wet Bulb Temperature 74 F

Procedure 9-MODE Barometer, in Hg 28.86 Dry Bulb Temperature 86 F

Run 2

Mode	Engine Speed, rpm	Observed Power, hp	Fuel, lbm/hr	Air, lbm/hr	Temperature, °F		Wet Concentrations					
					Intake	Exhaust	FIA HC, ppmC	NDIR HC, ppmC6	NDIR CO, %	NDIR CO2, %	NDIR NO, ppm	Polar. O2, %
1	3600	3.34	1.79	24.7	91	720	5,150	337	2.75	9.86	687	1.3
2	3600	1.70	1.56	19.6	91	670	6,200	415	4.63	8.42	153	1.1
3	3600	0.09	1.05	15.7	91	605	3,500	213	0.49	11.7	303	1.1
4	3600	3.60	2.25	25.5	92	705	7,600	446	6.65	7.04	103	0.9
5	3600	1.82	1.87	21.0	92	630	8,200	485	6.73	6.89	89	0.9
6	3600	0.11	1.22	15.7	93	570	5,000	324	3.99	9.31	118	0.9
7	3600	3.40	1.71	25.2	94	770	2,700	221	0.70	11.3	1740	1.1
8	3600	1.70	1.48	20.2	94	705	5,000	318	2.84	9.72	505	1.1
9	3600	0.10	1.20	16.8	94	630	5,000	195	0.65	11.5	541	1.2
10												
11												
12												
13												

Engine BRIGGS & STRATTON 92908 Date 4/29/71 Wet Bulb Temperature 72 F

Procedure 9-MODE Barometer, in Hg 28.83 Dry Bulb Temperature 88 F

Run 3

Mode	Engine Speed, rpm	Observed Power, hp	Fuel, lbm/hr	Air, lbm/hr	Temperature, °F		Wet Concentrations					
					Intake	Exhaust	FIA HC, ppmC	NDIR HC, ppmC6	NDIR CO, %	NDIR CO2, %	NDIR NO, ppm	Polar. O2, %
1	3600	3.03	1.81	24.3	94	740	5,500	389	2.64	11.0	1200	0.7
2	3600	1.49	1.33	19.8	92	695	4,200	260	0.34	12.1	1250	1.1
3	3600	0.07	1.19	17.5	90	665	4,300	241	0.27	11.1	275	3.1
4	3600	3.04	2.19	24.3	91	720	9,400	517	7.16	7.90	198	0.6
5	3600	1.73	1.50	19.8	91	670	4,600	412	3.13	10.6	663	0.5
6	3600	0.07	1.06	15.8	91	620	3,800	251	0.43	12.3	456	1.1
7	3600	2.99	1.65	24.3	92	760	5,000	273	0.70	12.1	2110	1.1
8	3600	1.46	1.32	19.8	92	700	4,500	252	0.28	12.0	1315	1.2
9	3600	0.08	1.10	18.1	91	650	3,400	197	0.27	10.9	384	2.8
10												
11												
12												
13												

Engine BRIGGS & STRATTON 92908 Date 4/30/71 Wet Bulb Temperature 68 F

Procedure 9-MODE Barometer, in Hg 29.03 Dry Bulb Temperature 85 F

Run 4

Mode	Engine Speed, rpm	Observed Power, hp	Fuel, lbm/hr	Air, lb_m/hr	Temperature, °F		Wet Concentrations					
					Intake	Exhaust	FIA HC, ppmC	NDIR HC, ppmC_6	NDIR CO, %	NDIR CO_2, %	NDIR NO, ppm	Polar. O_2, %
1	3600	3.10	1.68	22.9	82	720	5,500	345	1.99	11.0	1200	0.6
2	3600	1.52	1.25	18.9	83	650	4,500	274	0.19	12.1	1020	1.2
3	3600	0.09	1.06	17.2	83	610	[illegible],500	227	0.19	11.3	289	2.7
4	3100	3.34	1.88	20.6	83	600	9,100	605	7.56	6.55	82	1.1
5	3100	1.74	1.06	16.0	84	570	4,000	283	0.21	12.0	1020	1.3
6	3100	0.09	0.87	14.9	84	540	6,600	405	0.19	10.6	172	3.8
7	2600	2.98	1.62	17.2	84	520	9,000	744	8.80	5.59	53	1.5
8	2600	1.47	0.83	12.6	84	470	4,400	348	0.34	11.7	870	1.5
9	2600	0.07	0.62	9.2	84	370	6,400	395	0.44	11.7	184	1.3
10	2300	2.63	1.28	14.3	84	450	9,000	792	7.91	6.11	124	1.7
11	2300	1.34	0.67	10.3	84	400	4,300	387	0.29	11.5	626	1.7
12	2300	0.07	0.50	8.0	85	340	7,500	571	0.34	10.7	127	2.7
13	3600	2.94	1.92	23.2	89	730	7,500	427	5.07	8.39	254	0.8
14	3600	1.41	1.26	18.7	90	700	4,700	243	0.34	12.0	1130	1.0
15	3600	0.08	1.09	17.0	90	690	3,600	187	0.19	11.7	444	1.8

Engine BRIGGS & STRATTON 92908 Date 5/4/71 Wet Bulb Temperature 69 F

Procedure 30-MODE MAPPING Barometer, in Hg 29.00 Dry Bulb Temperature 83 F

Modes 1-15

Mode	Engine Speed, rpm	Observed Power, hp	Fuel, lb_m/hr	Air, lb_m/hr	Temperature, °F Intake	Temperature, °F Exhaust	Wet Concentrations FIA HC, ppmC	Wet Concentrations NDIR HC, ppmC_6	Wet Concentrations NDIR CO, %	Wet Concentrations NDIR CO_2, %	Wet Concentrations NDIR NO, ppm	Wet Concentrations Polar. O_2, %
16	3100	3.13	1.97	20.4	91	660	3,100	656	8.80	5.59	68	1.2
17	3100	1.60	1.04	15.8	90	640	3,100	302	0.54	11.7	961	1.2
18	3100	0.08	0.84	12.4	91	570	3,100	204	0.34	12.0	287	1.0
19	2600	2.79	1.70	17.5	90	590	2,600	672	9.20	5.12	91	1.5
20	2600	1.45	0.84	13.0	92	610	2,600	294	0.24	11.7	853	1.6
21	2600	0.07	0.62	9.1	91	500	2,600	273	0.75	11.9	198	1.1
22	3600	2.92	1.62	23.2	90	730	3,600	238	1.03	11.5	1590	0.9
23	3600	1.49	1.32	20.4	91	670	3,600	205	0.14	11.7	1180	1.6
24	3600	0.08	1.06	17.5	90	620	3,600	207	0.14	10.8	261	2.7
25	3100	3.32	1.72	20.9	91	620	3,100	446	5.95	7.76	167	1.5
26	3100	1.68	1.04	17.0	91	590	3,100	232	0.12	11.1	1050	2.5
27	3100	0.07	0.80	13.6	91	550	3,100	383	0.14	10.0	158	4.3
28	2600	2.98	1.53	17.5	92	520	2,600	630	7.44	6.14	89	1.9
29	2600	1.49	0.81	13.0	93	470	2,600	295	0.14	11.3	431	2.2
30	2600	0.05	0.66	10.8	94	400	2,600	268	0.14	11.1	178	2.8

Engine BRIGGS & STRATTON 92908 Date 5/4/71 Wet Bulb Temperature 69 F

Procedure 30-MODE MAPPING Barometer, in Hg 29.00 Dry Bulb Temperature 83 F

Modes 16-30

Mode	Engine Speed, rpm	Observed Power, hp	Fuel, lbm/hr	Air, lb_m/hr	Temperature, °F		Wet Concentrations					
					Intake	Exhaust	FIA HC, ppmC	NDIR HC, ppmC_6	NDIR CO, %	NDIR CO_2, %	NDIR NO, ppm	Polar. O_2, %
1	3600	2.85	2.13	30.2	77	810	2,500	210	1.44	12.2	2090	0.5
2	3600	1.50	1.39	20.7	76	650	2,000	119	0.28	12.5	1310	0.8
3	3600	0.25	0.90	13.0	77	470	4,100	218	0.96	12.6	262	0.8
4	3600	2.85	2.40	30.8	77	770	3,300	149	4.14	10.4	957	0.4
5	3600	1.50	1.52	20.1	77	610	4,100	183	3.03	11.0	781	0.5
6	3600	0.20	0.96	12.4	77	420	6,000	216	3.75	10.4	103	0.6
7	3600	2.90	2.09	30.8	78	810	2,200	90	0.58	12.5	2440	0.8
8	3600	1.55	1.38	22.5	78	660	1,600	67	0.17	11.7	1180	2.2
9	3600	0.25	0.92	14.8	78	500	4,000	144	0.59	11.7	190	2.7
10												
11												
12												
13												

Engine BRIGGS & STRATTON 100202 Date 4/6/71 Wet Bulb Temperature 53 F

Procedure 9-MODE Barometer, in Hg 29.45 Dry Bulb Temperature 74 F

Run 1

Mode	Engine Speed, rpm	Observed Power, hp	Fuel, lbm/hr	Air, lbm/hr	Temperature, °F		Wet Concentrations					
					Intake	Exhaust	FIA HC, ppmC	NDIR HC, ppmC6	NDIR CO, %	NDIR CO2, %	NDIR NO, ppm	Polar. O2, %
1	3600	3.05	2.21	30.5	80	790	3,100	193	1.88	11.3	1960	0.4
2	3600	1.65	1.47	22.3	80	660	2,000	120	0.19	11.7	1380	1.0
3	3600	0.30	0.87	12.3	80	470	4,800	202	1.20	12.0	264	0.7
4	3600	2.95	2.48	30.5	80	760	3,600	208	4.90	9.57	734	0.3
5	3600	1.55	1.50	20.0	80	600	4,000	209	2.97	10.8	1000	0.5
6	3600	0.25	0.97	12.3	80	430	5,700	287	4.37	9.62	89	0.8
7	3600	2.90	2.09	30.5	80	800	2,400	119	0.70	12.1	2490	0.7
8	3600	1.55	1.45	22.9	80	670	1,800	88	0.17	13.3	1210	1.6
9	3600	0.30	0.78	12.3	80	440	4,500	169	0.64	12.0	278	2.6
10												
11												
12												
13												

Engine BRIGGS & STRATTON 100202 Date 4/7/71 Wet Bulb Temperature 54 F

Procedure 9-MODE Barometer, in Hg 29.35 Dry Bulb Temperature 79 F

Run 2

							Wet Concentrations					
Mode	Engine Speed, rpm	Observed Power, hp	Fuel, lbm/hr	Air, lb_m/hr	Temperature, °F Intake	Temperature, °F Exhaust	FIA HC, ppmC	NDIR HC, ppmC$_6$	NDIR CO, %	NDIR CO$_2$, %	NDIR NO, ppm	Polar. O$_2$, %
1	3600	13.2	10.3	127.	80	810	4,050	208	5.51	9.00	469	0.7
2	3600	6.7	6.3	82.5	78	700	3,400	180	3.97	9.92	347	1.0
3	3600	0.2	4.3	51.4	78	660	5,600	233	6.75	7.70	77	1.5
4	3600	13.4	10.9	127.	79	785	4,300	263	6.65	8.10	248	0.7
5	3600	6.9	6.6	83.7	80	760	3,800	200	4.69	9.59	273	0.7
6	3600	0.2	4.5	52.0	79	620	6,300	281	7.20	7.29	67	1.3
7	3600	13.7	10.0	126.	81	800	3,700	162	4.69	9.50	850	0.6
8	3600	6.9	6.2	84.9	80	740	3,400	155	3.27	10.2	398	1.2
9	3600	0.2	4.2	53.7	80	470	5,050	201	5.48	8.35	89	1.7
10												
11												
12												
13												

Engine KOHLER K-482 Date 3/1/71 Wet Bulb Temperature 67 F

Procedure 9-MODE Barometer, in Hg 28.99 Dry Bulb Temperature 73 F

Run 1

	Engine	Observed					Wet Concentrations					
	Speed,	Power,	Fuel,	Air,	Temperature, °F		FIA	NDIR	NDIR	NDIR	NDIR	Polar.
Mode	rpm	hp	lb_m/hr	lb_m/hr	Intake	Exhaust	HC, ppmC	HC, ppmC_6	CO, %	CO_2, %	NO, ppm	O_2, %
1	3600	14.8	12.1	137.	80	895	4,400	190	5.37	9.17	510	0.5
2	3600	7.5	7.65	86.7	80	780	3,600	165	4.56	9.96	495	0.8
3	3600	0.2	5.03	50.2	80	575	6,500	254	7.17	7.67	67	1.5
4	3600	15.0	12.3	137.	82	875	4,800	211	6.13	8.86	414	0.5
5	3600	7.6	7.50	86.7	82	755	4,000	158	4.04	10.1	418	0.8
6	3600	0.2	5.00	50.2	80	575	7,200	258	7.17	7.67	60	1.5
7	3600	14.7	11.0	137.	81	915	3,800	142	3.34	10.5	1115	0.5
8	3600	7.5	6.88	89.6	82	810	2,400	82	1.33	11.5	774	0.9
9	3600	0.3	4.79	49.6	80	570	5,000	270	5.41	8.51	124	1.6
10												
11												
12												
13												

Engine KOHLER K482

Date 3/24/71

Wet Bulb Temperature 60 F

Procedure 9-MODE

Barometer, in Hg 29.00

Dry Bulb Temperature 72 F

Run 2

Mode	Engine Speed, rpm	Observed Power, hp	Fuel, lbm/hr	Air, lb_m/hr	Temperature, °F		Wet Concentrations					
					Intake	Exhaust	FIA HC, ppmC	NDIR HC, $ppmC_6$	NDIR CO, %	NDIR CO_2, %	NDIR NO, ppm	Polar. O_2, %
1	4500	1.58	1.97	24.5	88	660	39,000	3910	2.18	8.29	217	4.6
2	4500	0.91	1.36	17.1	89	600	31,800	3140	2.78	8.82	113	3.9
3	4500	0.27	0.91	12.0	89	560	26,100	2600	3.27	8.94	90	3.2
4	4500	1.60	2.35	24.5	89	615	41,400	3780	5.21	6.70	91	4.5
5	4500	0.93	1.75	18.0	89	580	39,000	3700	5.89	6.44	83	3.9
6	4500	0.28	1.15	12.6	90	535	42,900	3780	5.15	6.70	91	3.8
7	4500	1.60	1.89	24.3	90	640	38,400	3720	0.82	8.98	342	4.9
8	4500	0.93	1.42	18.3	90	630	32,400	2950	0.82	9.76	172	4.5
9	4500	0.27	0.92	11.4	90	620	25,800	2310	2.23	9.46	112	3.4
10												
11												
12												
13												

Engine TECUMSEH AH520 T1448 Date 4/12/71 Wet Bulb Temperature 66 F

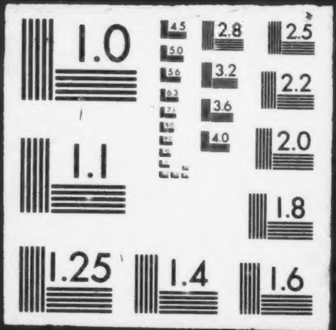
Procedure 9-MODE Barometer, in Hg 29.13 Dry Bulb Temperature 86 F

Run 1

2 OF 2

PB

224885/4


1.0
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2.0
1.1
1.8
1.25
1.4
1.6

Mode	Engine Speed, rpm	Observed Power, hp	Fuel, lbm/hr	Air, lb_m/hr	Temperature, °F		Wet Concentrations					
					Intake	Exhaust	FIA HC, ppmC	NDIR HC, $ppmC_6$	NDIR CO, %	NDIR CO_2, %	NDIR NO, ppm	Polar. O_2, %
1	4500	1.74	2.04	24.7	84	630	39,600	3610	2.40	8.44	216	4.9
2	4500	0.99	1.48	17.2	84	630	28,500	2560	3.05	9.05	133	3.4
3	4500	0.28	0.87	10.9	84	560	24,600	2030	2.57	9.35	112	3.2
4	4500	1.67	2.44	24.7	85	625	42,600	4520	5.78	6.24	84	4.3
5	4500	0.96	1.62	18.1	85	590	31,200	3010	6.07	7.83	103	3.1
6	4500	0.28	1.01	11.5	85	525	34,800	3010	4.68	7.47	105	3.1
7	4500	1.61	1.81	23.8	85	650	36,900	2920	0.50	9.44	469	5.1
8	4500	0.94	1.32	19.0	86	670	29,100	2330	0.58	10.1	307	4.0
9	4500	0.28	0.80	11.2	86	600	27,000	2090	1.35	9.90	290	3.4
10												
11												
12												
13												

Engine TECUMSEH AH520 T1448 Date 4/13/71 Wet Bulb Temperature 66 F

Procedure 9-MODE Barometer, in Hg 29.12 Dry Bulb Temperature 84 F

Run 2

Mode	Engine Speed, rpm	Observed Power, hp	Fuel, lbm/hr	Air, lb_m/hr	Temperature, °F		Wet Concentrations					
					Intake	Exhaust	FIA HC, ppmC	NDIR HC, $ppmC_6$	NDIR CO, %	NDIR CO_2, %	NDIR NO, ppm	Polar. O_2, %
1	3600	1.43	2.08	24.0	88	610	52,800	4610	3.00	6.99	218	6.4
2	3600	0.82	1.36	15.4	88	530	37,200	4180	3.85	7.92	112	4.2
3	3600	0.22	0.70	8.6	89	440	33,000	3190	3.38	8.44	84	3.7
4	3600	1.45	2.37	24.0	89	570	60,000	5660	5.15	5.73	49	6.1
5	3600	0.86	1.70	16.6	88	530	47,400	5110	6.38	5.93	76	4.3
6	3600	0.22	0.73	8.6	88	450	36,000	4015	4.15	7.67	91	3.6
7	3600	1.41	1.76	24.0	89	620	46,800	4570	0.50	8.34	610	6.4
8	3600	0.80	1.14	14.9	89	560	36,600	4050	1.96	9.06	142	4.0
9	3600	0.22	0.70	8.6	89	440	34,800	3435	3.95	8.07	105	3.5
10												
11												
12												
13												

Engine TECUMSEH AH520 T1448 Date 4/14/71 Wet Bulb Temperature 64 F

Procedure 9-MODE Barometer, in Hg 29.12 Dry Bulb Temperature 86 F

Run 3

Mode	Engine Speed, rpm	Observed Power, hp	Fuel, lbm/hr	Air, lbm/hr	Temperature, °F		Wet Concentrations					
					Intake	Exhaust	FIA HC, ppmC	NDIR HC, ppmC6	NDIR CO, %	NDIR CO2, %	NDIR NO, ppm	Polar. O2, %
1	3600	9.3	7.86	91.2	88	980	3,600	88	5.62	8.99	510	—
2	3600	4.7	5.02	62.5	88	850	4,100	108	6.14	8.78	207	—
3	3600	0.6	3.37	37.9	86	700	5,400	120	5.74	8.98	123	—
4	3600	9.5	8.55	91.8	88	960	4,200	116	6.93	8.08	309	—
5	3600	4.7	6.03	63.7	89	830	5,100	151	8.12	7.60	128	—
6	3600	0.5	3.56	36.7	88	650	6,400	156	6.84	8.40	108	—
7	3600	9.4	6.77	91.2	89	1030	3,000	62	3.29	11.0	1150	—
8	3600	4.8	4.93	63.1	89	880	3,600	81	4.46	9.97	417	—
9	3600	0.3	2.51	36.7	88	750	3,800	73	2.97	10.8	152	—
10												
11												
12												
13												

Engine WISCONSIN S-12D

Date 3/30/71

Wet Bulb Temperature 57 F

Procedure 9-MODE

Barometer, in Hg 29.12

Dry Bulb Temperature 82 F

Run 1

Mode	Engine Speed, rpm	Observed Power, hp	Fuel, lbm/hr	Air, lbm/hr	Temperature, °F		Wet Concentrations					
					Intake	Exhaust	FIA HC, ppmC	NDIR HC, ppmC6	NDIR CO, %	NDIR CO2, %	NDIR NO, ppm	Polar. O2, %
1	3600	9.5	7.41	91.9	88	1030	3,200	132	5.12	9.54	510	0.5
2	3600	4.8	5.60	64.9	88	900	4,200	165	6.57	8.34	158	0.4
3	3600	0.3	3.40	38.3	88	730	5,500	207	6.70	8.25	81	0.6
4	3600	9.5	8.36	93.0	88	970	4,000	173	7.00	8.07	221	0.3
5	3600	4.8	6.46	67.1	88	880	5,300	249	8.26	6.93	95	0.3
6	3600	0.3	3.78	40.0	88	700	7,700	301	8.17	6.93	60	0.6
7	3600	9.6	6.96	94.2	90	1070	2,700	93	2.97	10.8	1020	0.4
8	3600	4.9	5.03	64.9	91	930	3,200	105	4.05	10.0	404	0.4
9	3600	0.3	2.90	40.0	91	770	4,000	133	4.05	10.0	151	0.7
10												
11												
12												
13												

Engine WISCONSIN S-12D Date 3/31/71 Wet Bulb Temperature 72 F

Procedure 9-MODE Barometer, in Hg 28.93 Dry Bulb Temperature 84 F

Run 2

APPENDIX C

Graphical Representation of Emissions During Transient Conditions

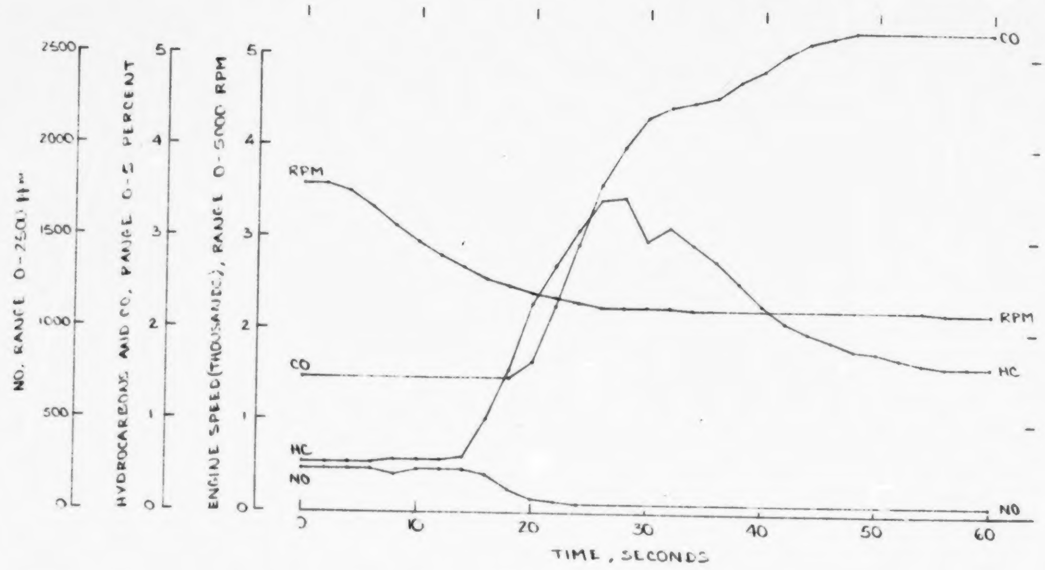

FIGURE C-1. TRANSITION BETWEEN 3600 RPM (NO LOAD) AND 2200 RPM (NO LOAD) FOR THE BRIGGS & STRATTON 100202 ENGINE (RUN T1A) – CONSTANT LOAD, THROTTLE CLOSING

Reproduced from best available copy.

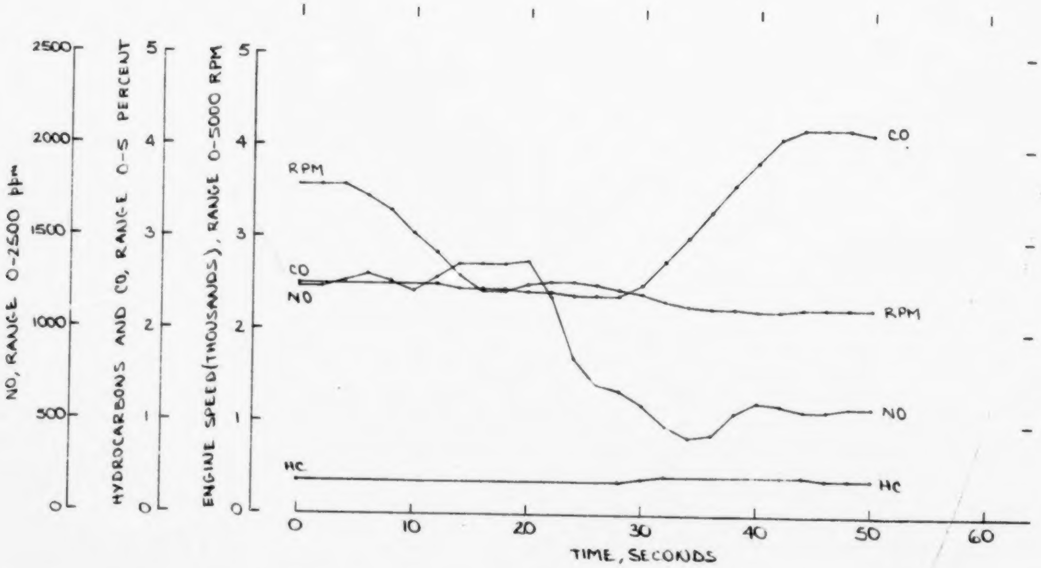

FIGURE C-2. TRANSITION BETWEEN 3600 RPM (FULL LOAD) AND 2250 RPM (FULL LOAD) FOR THE BRIGGS & STRATTON 100202 ENGINE (RUN T2C) — CONSTANT THROTTLE, LOAD INCREASING

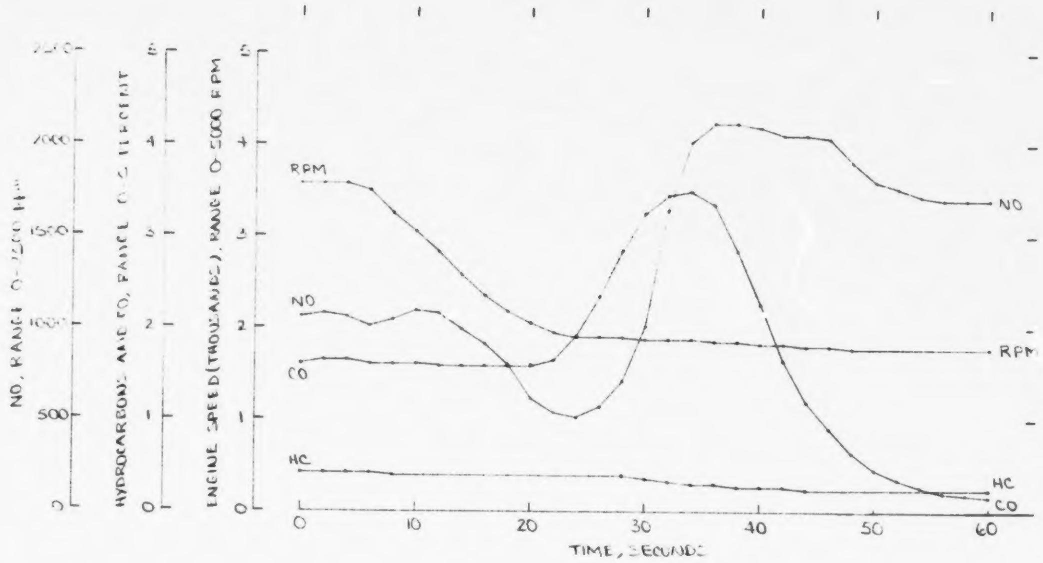

FIGURE C-3. TRANSITION BETWEEN 3600 RPM (HALF LOAD) AND 1800 RPM (HALF LOAD) FOR THE BRIGGS & STRATTON 100202 ENGINE (RUN T3B) — CONSTANT THROTTLE, LOAD INCREASING

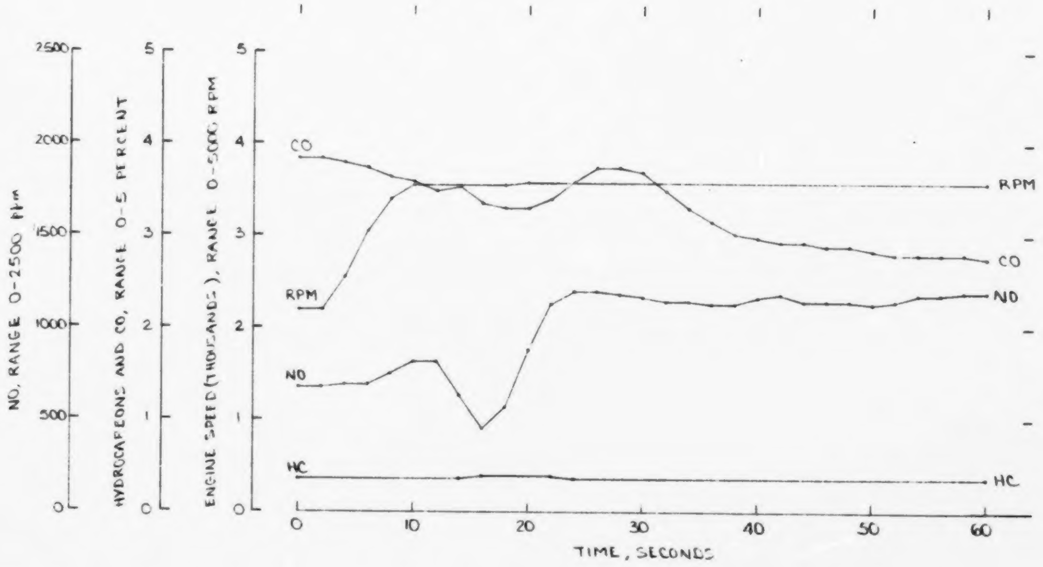

FIGURE C-4. TRANSITION BETWEEN 2200 RPM (FULL LOAD) AND 3575 RPM (FULL LOAD) FOR THE BRIGGS & STRATTON 100202 ENGINE (RUN T4A) — CONSTANT THROTTLE, DECREASING LOAD

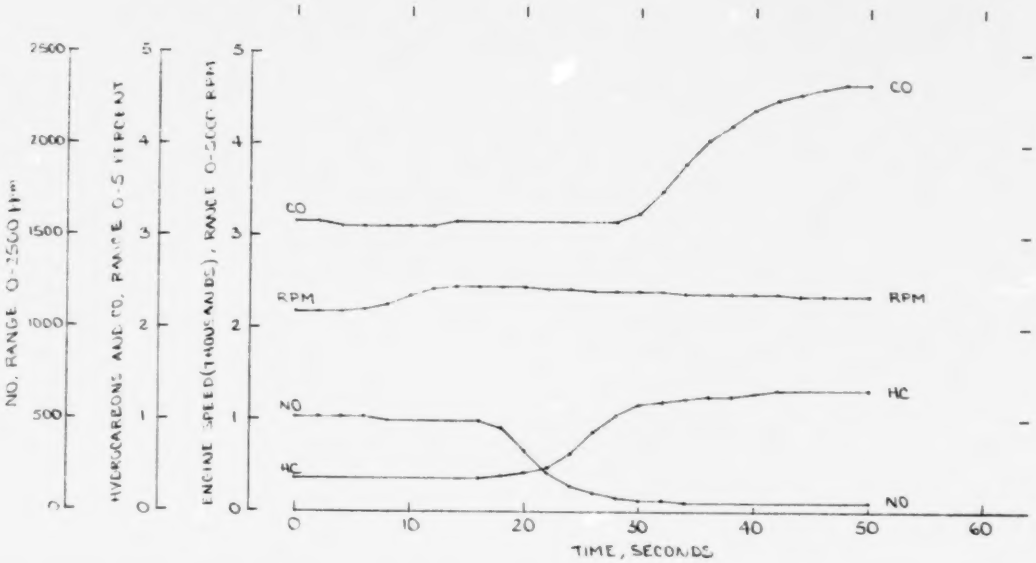

FIGURE C-5. TRANSITION BETWEEN 2200 RPM (HALF LOAD) AND 2350 RPM (NO LOAD) FOR THE BRIGGS & STRATTON 100202 ENGINE (RUN T5A) — CONSTANT THROTTLE, DECREASING LOAD (GOVERNOR CONTROLLED ENGINE SPEED DURING THIS TRANSIENT CONDITION)

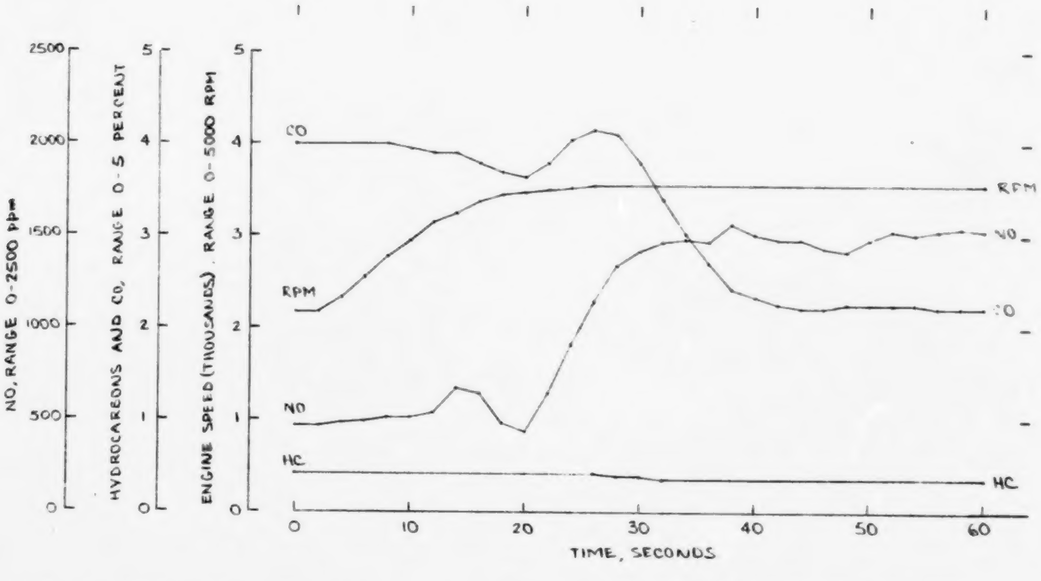

FIGURE C-6. TRANSITION BETWEEN 2200 RPM (PART LOAD) AND 3600 RPM (FULL LOAD) FOR THE BRIGGS & STRATTON 100202 ENGINE (RUN T6A) — CONSTANT LOAD, THROTTLE BEING OPENED

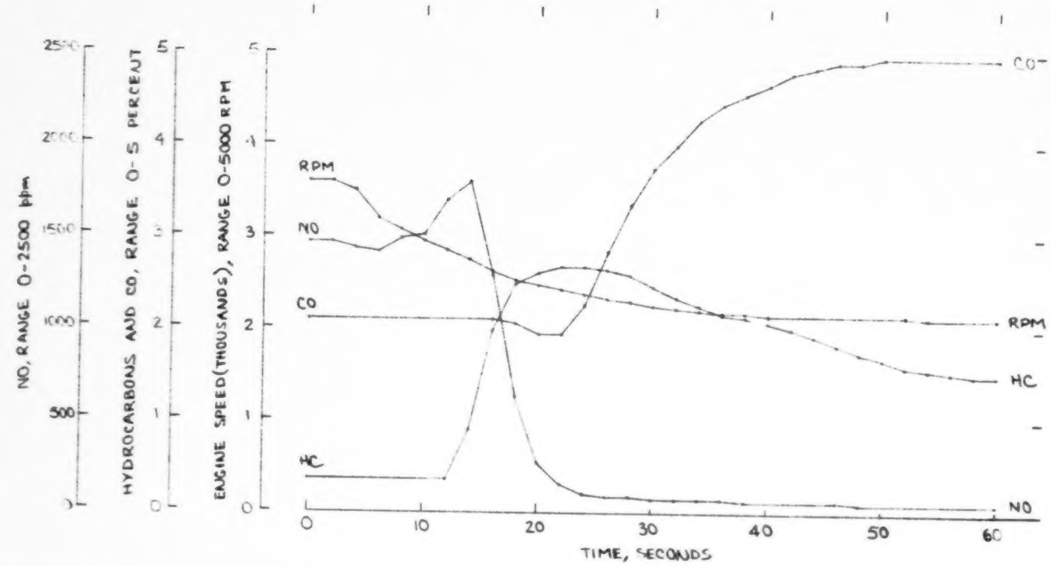

FIGURE C-7. TRANSITION BETWEEN 3600 RPM (FULL LOAD) AND 2125 RPM (NO LOAD) FOR THE BRIGGS & STRATTON 100202 ENGINE (RUN T7B) — THROTTLE CLOSING, LOAD DECREASING

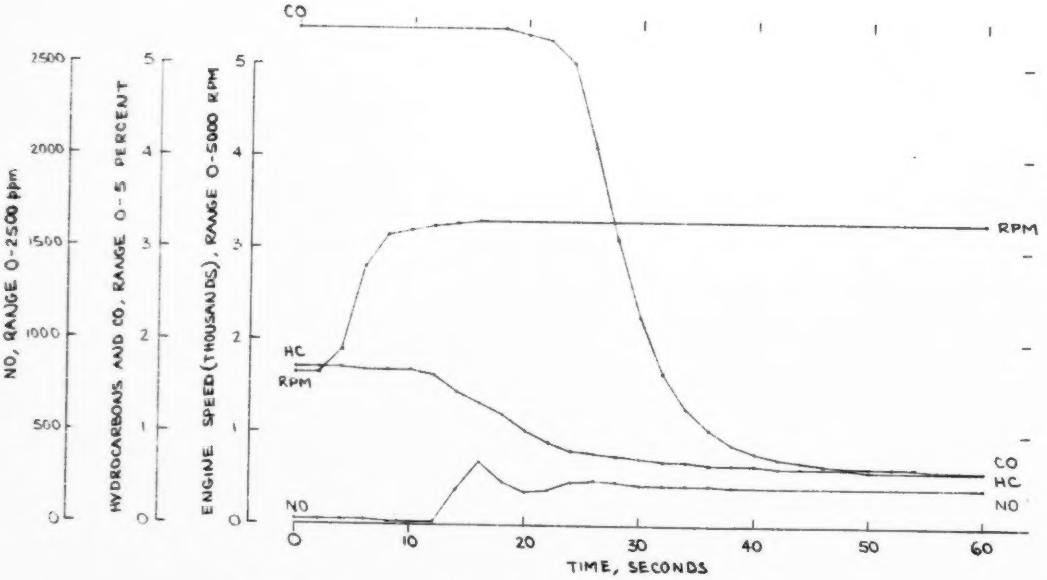

FIGURE C-8. TRANSITION BETWEEN 1650 RPM (NO LOAD) AND 3300 RPM (NO LOAD) FOR THE BRIGGS & STRATTON 100202 ENGINE (RUN T8C) — CONSTANT LOAD, THROTTLE BEING OPENED

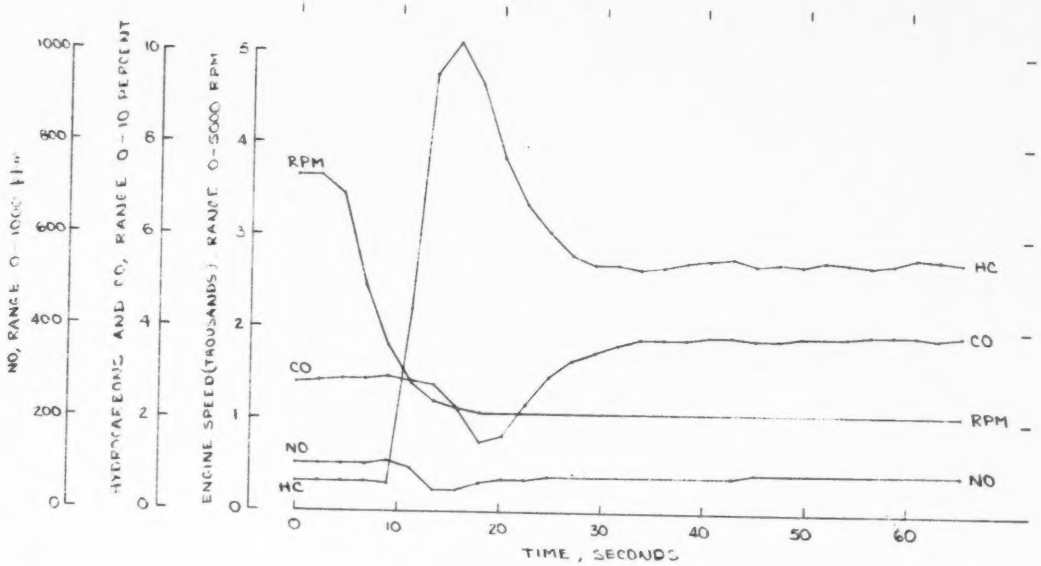

FIGURE C-9. TRANSITION BETWEEN 3650 RPM (NO LOAD) AND IDLE (NO LOAD) FOR THE KOHLER K482 ENGINE (RUN T1B) — CONSTANT LOAD, THROTTLE CLOSING

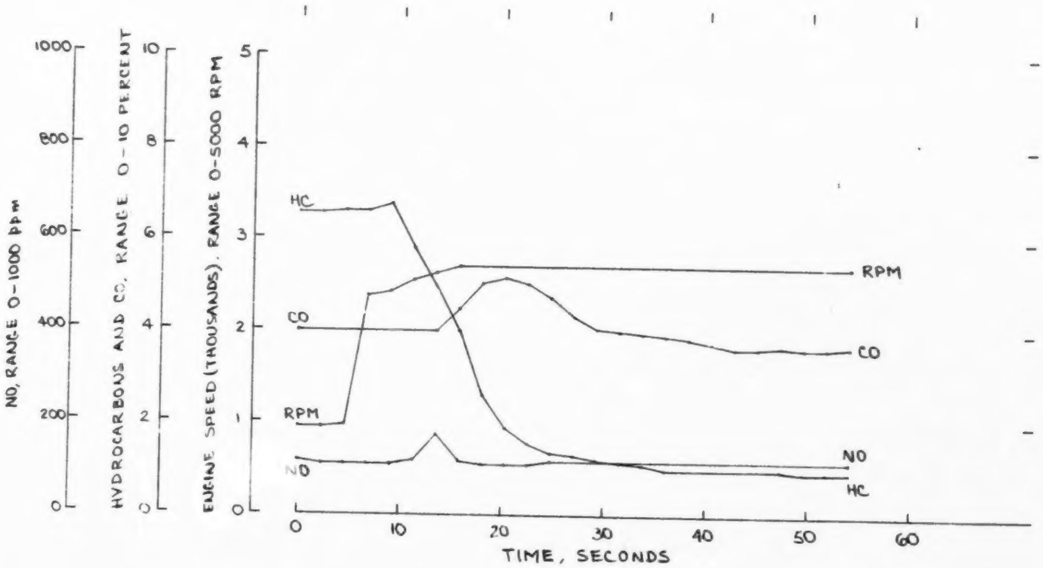

FIGURE C-10. TRANSITION BETWEEN IDLE (NO LOAD) AND 2700 RPM (NO LOAD) FOR THE KOHLER K482 ENGINE (RUN T2B) — CONSTANT LOAD, THROTTLE BEING OPENED

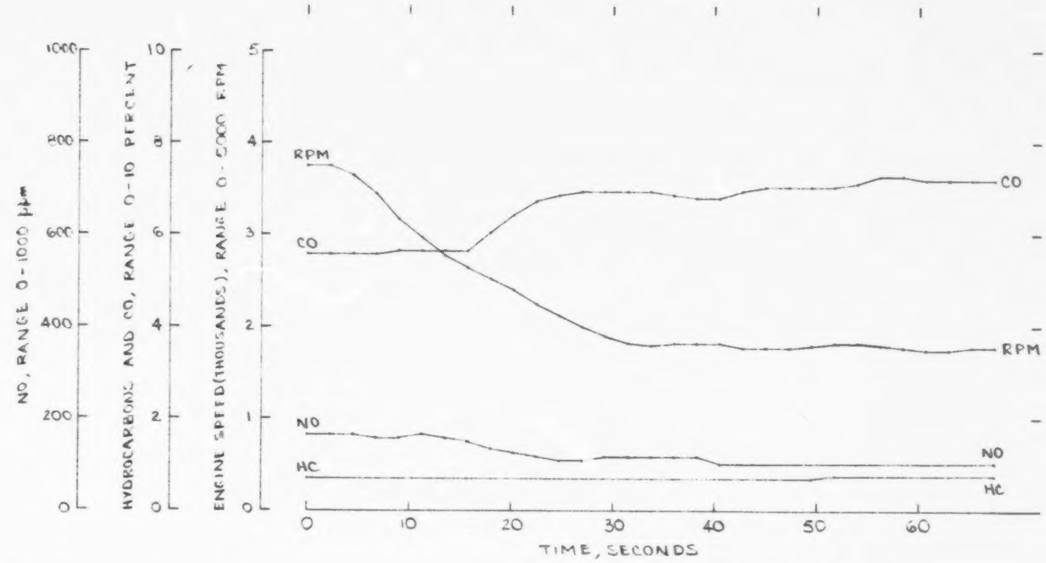

FIGURE C-11. TRANSITION BETWEEN 3750 RPM (FULL LOAD) AND 1800 RPM (FULL LOAD) FOR THE KOHLER K482 ENGINE (RUN T4B) — CONSTANT THROTTLE, LOAD INCREASING

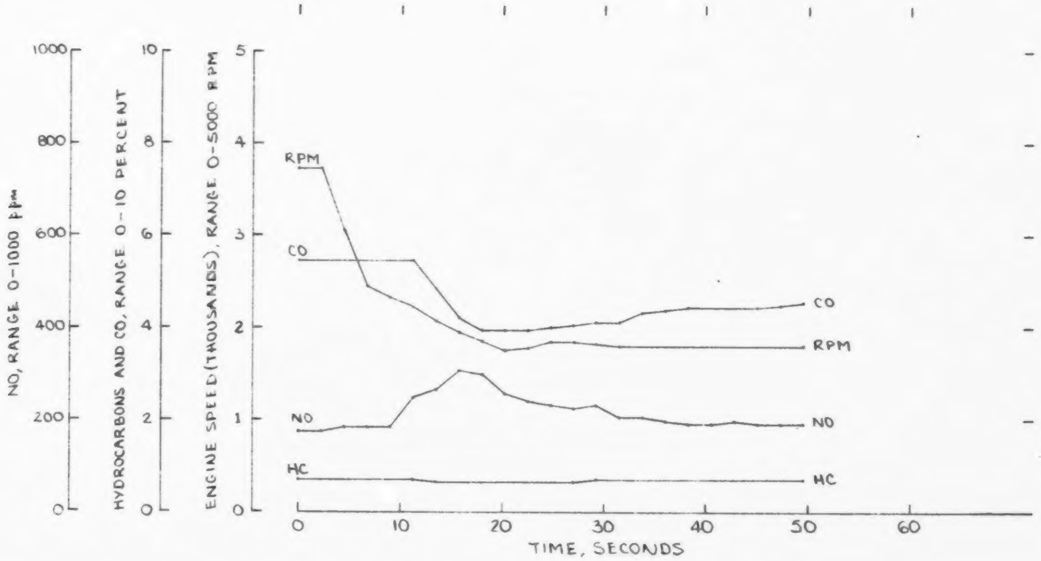

FIGURE C-12. TRANSITION BETWEEN 3725 RPM (FULL LOAD) AND 1800 RPM (PART LOAD) FOR THE KOHLER K482 ENGINE (RUN T7B) — CONSTANT LOAD, THROTTLE CLOSING

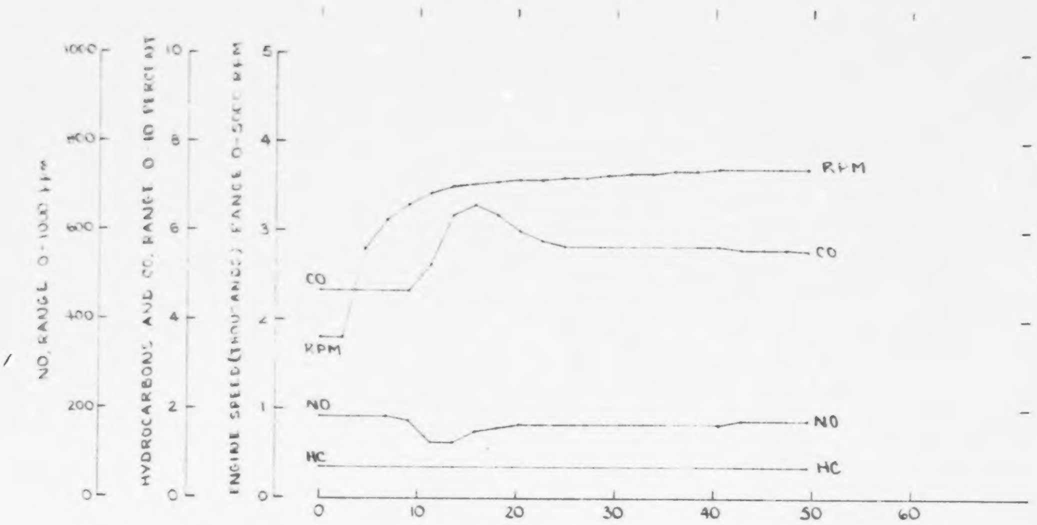

FIGURE C-13. TRANSITION BETWEEN 1800 RPM (PART LOAD) AND 3700 RPM (FULL LOAD) FOR THE KOHLER K482 ENGINE (RUN T9A) — CONSTANT LOAD, THROTTLE BEING OPENED

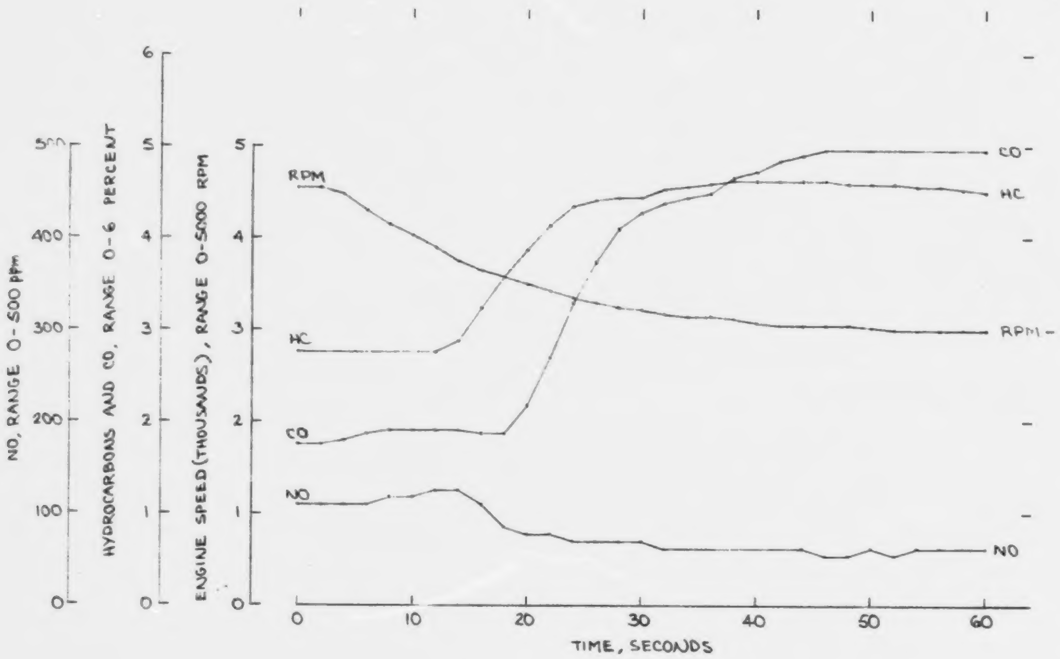

FIGURE C-14. TRANSITION BETWEEN 4500 RPM (NO LOAD) AND 3000 RPM (NO LOAD) FOR THE TECUMSEH AH520 TYPE 1448 ENGINE (RUN T1A) — CONSTANT LOAD, THROTTLE CLOSING

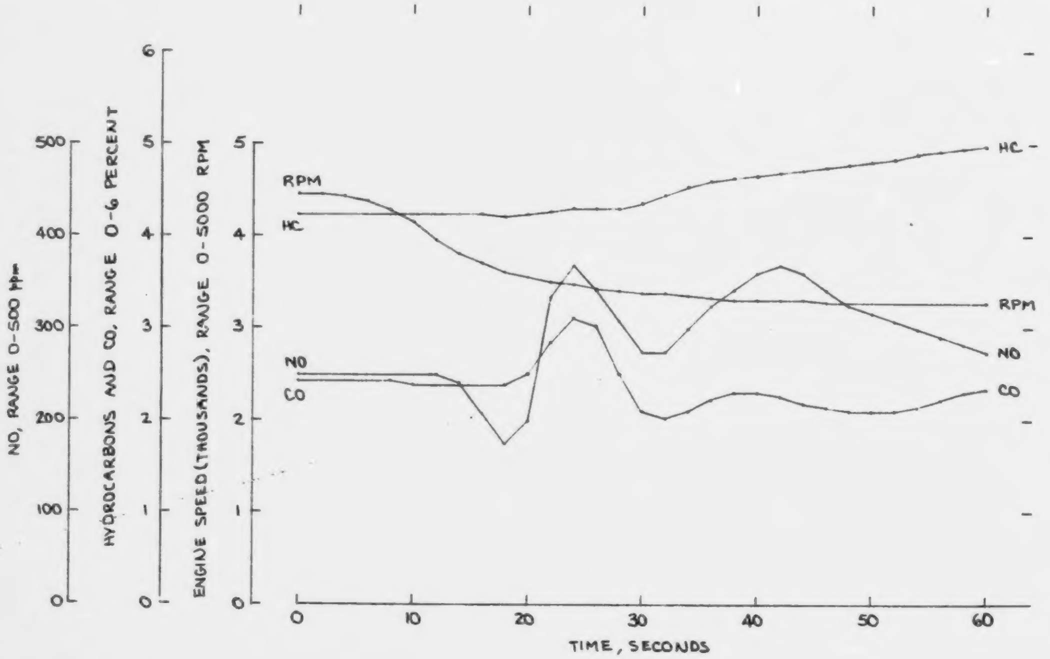

FIGURE C-15. TRANSITION BETWEEN 4500 RPM (FULL LOAD) AND 3300 RPM (FULL LOAD) FOR THE TECUMSEH AH520 TYPE 1448 ENGINE (RUN T2D) — CONSTANT THROTTLE, LOAD INCREASING

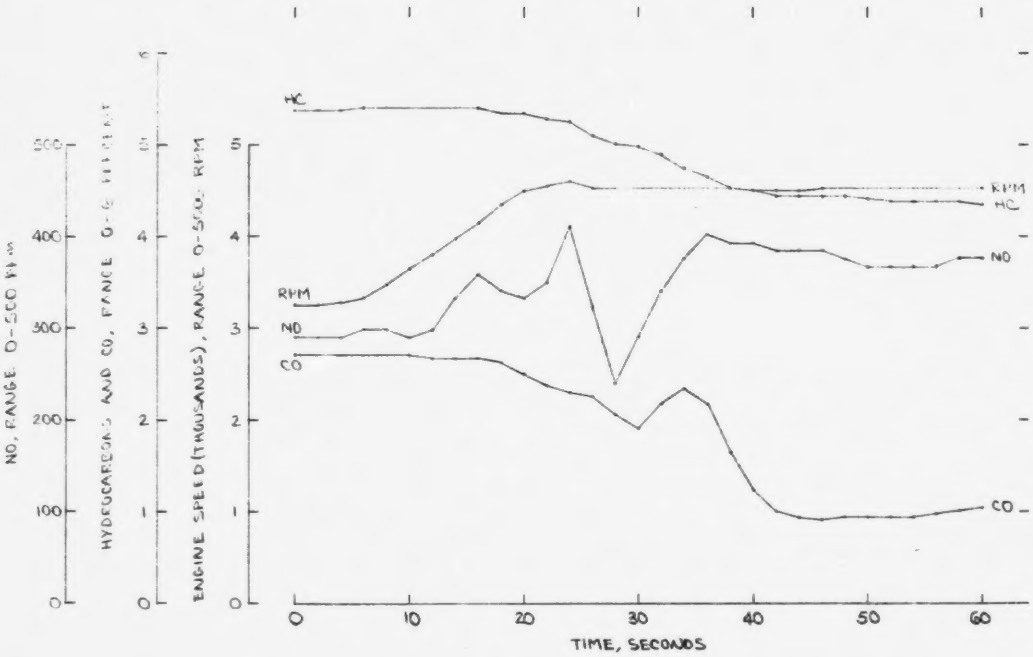

FIGURE C-16. TRANSITION BETWEEN 3300 RPM (FULL LOAD) AND 4500 RPM (FULL LOAD) FOR THE TECUMSEH AH520 TYPE 1448 ENGINE (RUN T4B) — CONSTANT THROTTLE, LOAD DECREASING

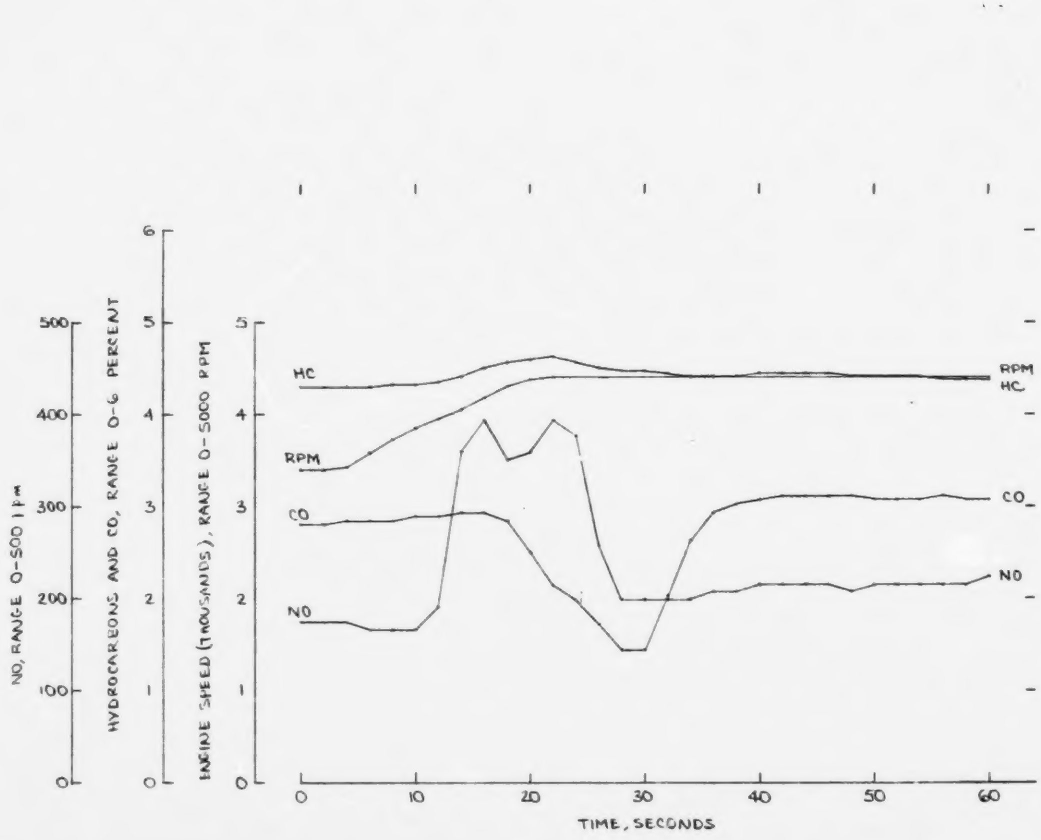

FIGURE C-17. TRANSITION BETWEEN 3400 RPM (FULL LOAD) AND 4400 RPM (FULL LOAD) FOR THE TECUMSEH AH520 TYPE 1448 ENGINE (RUN T6B) — CONSTANT THROTTLE, DECREASING LOAD

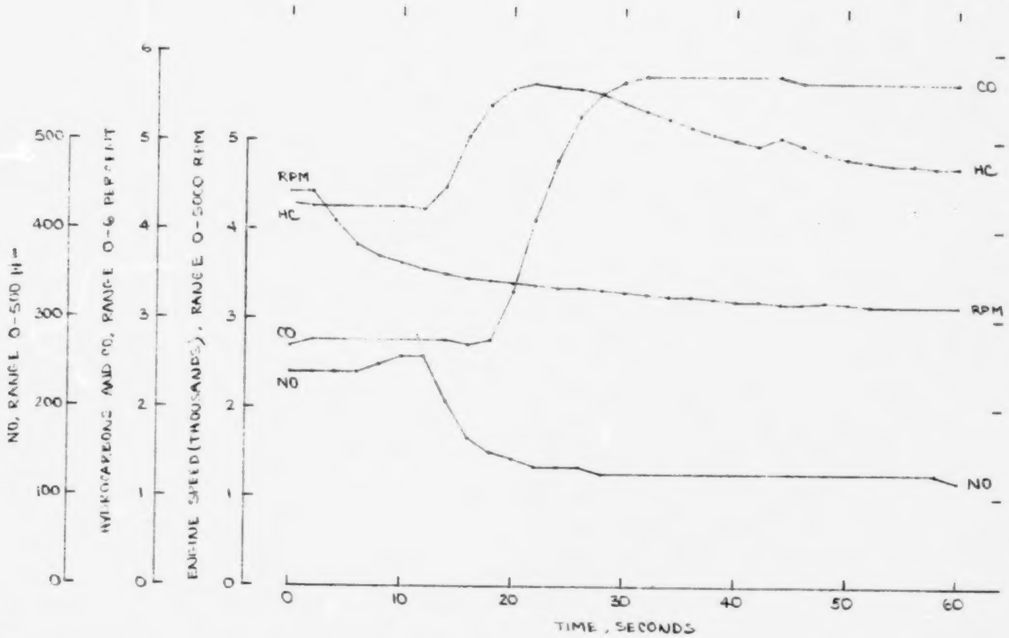

FIGURE C-18. TRANSITION BETWEEN 4500 RPM (FULL LOAD) AND 3200 RPM (NO LOAD) FOR THE TECUMSEH AH520 TYPE 1448 ENGINE (RUN T7A) — THROTTLE CLOSING, LOAD DECREASING

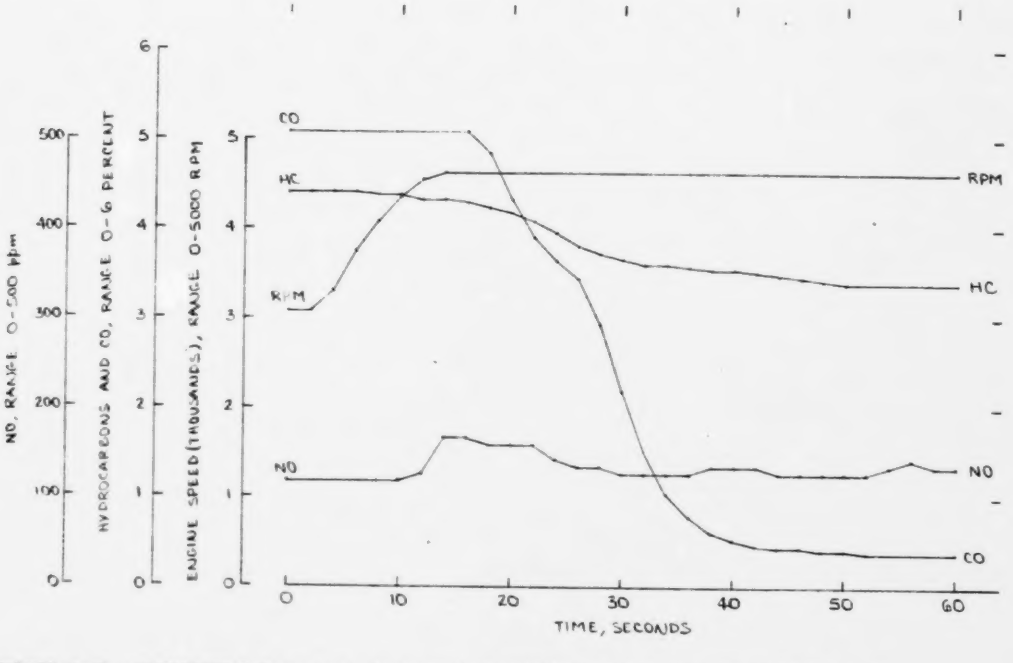

FIGURE C-19. TRANSITION BETWEEN 3100 RPM (NO LOAD) AND 4600 RPM (NO LOAD) FOR THE TECUMSEH AH520 TYPE 1448 ENGINE (RUN T8A) — CONSTANT LOAD, THROTTLE BEING OPENED

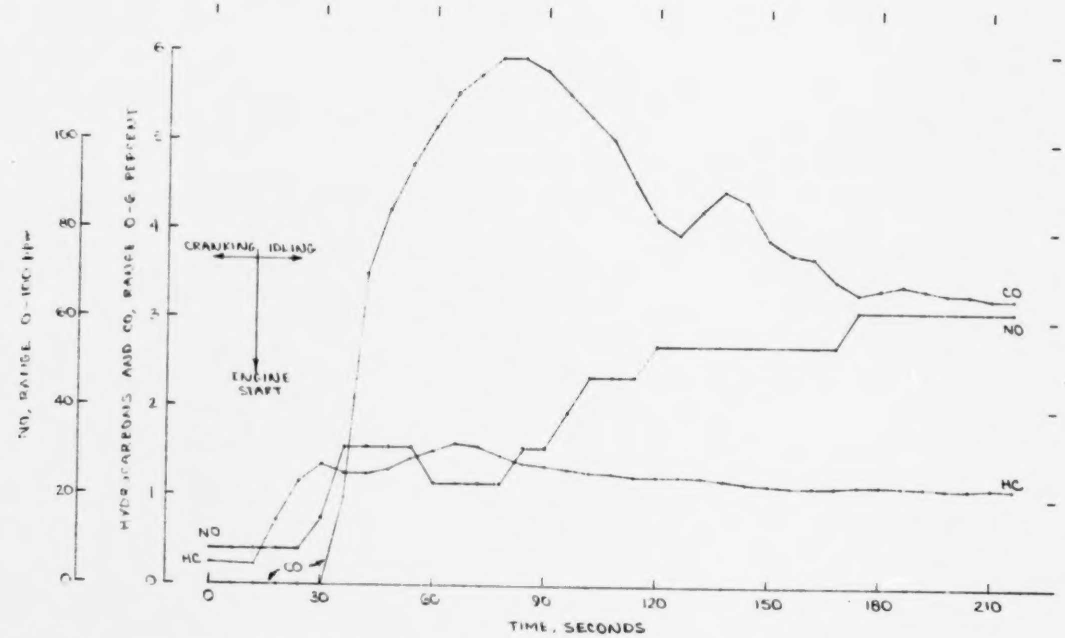

FIGURE C-20. COLD START AND IDLE FOR BRIGGS & STRATTON 92908 ENGINE, 4/30/71 (RUN CS1)

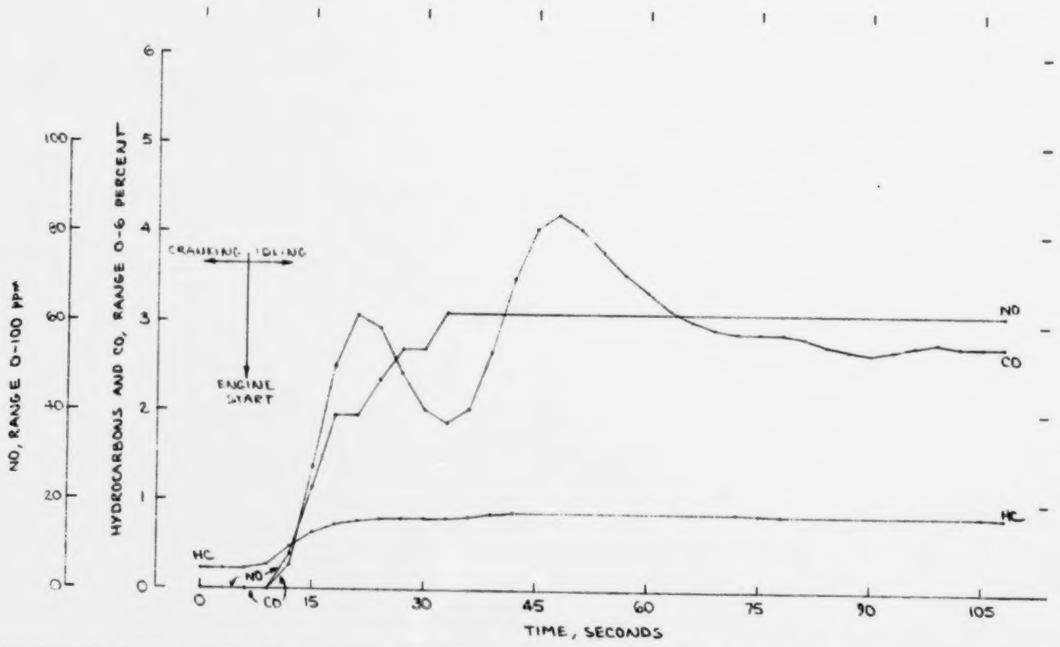

FIGURE C-21. COLD START AND IDLE FOR BRIGGS & STRATTON 92908 ENGINE, 5/4/71 (RUN CS2)